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From Maintenance To Stewardship: Green Stormwater Infrastructure Capacity In Vermont Towns & Design And Participatory Processes To Provide Cultural Ecosystem Services

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FROM MAINTENANCE TO STEWARDSHIP: GREEN STORMWATER INFRASTRUCTURE CAPACITY IN VERMONT TOWNS & DESIGN AND PARTICIPATORY PROCESSES TO PROVIDE CULTURAL ECOSYSTEM SERVICES

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ABSTRACT

The impervious surfaces of built landscapes create stormwater runoff that causes water quantity and quality problems downstream, upsetting natural hydrology and harming aquatic ecosystems. Green stormwater infrastructure (GSI) includes practices that reduce the amount of stormwater runoff and the pollutants it carries utilizing plants, soils, and other materials to capture, store, reuse, infiltrate, evapotranspire, and filter stormwater. GSI helps to restore developed landscapes, mimicking natural hydrologic processes and providing important water treatment functions as well as beneficial green spaces in urban areas. However, there are many challenges associated with the implementation and maintenance of GSI in our communities and cultures.

This research explores the human side of implementing GSI, investigating current maintenance capacities in rural and urban settings, and exploring multifunctional benefits of GSI to provide both biophysical and cultural ecosystem services (CES). Research goals include characterizing the current state of GSI implementation and maintenance in municipalities in the State of Vermont (USA) and eliciting lessons that can inform GSI design practices and policies. Multifunctional GSI design objectives that provide and enhance CES are described, revealing opportunities to instill values and a sense of stewardship for the health wellbeing of people and ecosystems.

The first chapter provides relevant topical background to set the stage for the latter two chapters. The second chapter analyzes results from a survey of municipal officials in Vermont that occurred as part of NSF-EPSCoR-funded Basin Resilience to Extreme Events project research on stormwater management. The survey included questions about GSI and maintenance practices in place and perceptions of visual appeal and ability to maintain bioretention systems shown in landscape visualizations. Results show that visual appeal and perceived maintainability of vegetated bioretention practices do not appear to be significant barriers to adoption and operation, but stormwater policy and funding are shown to be both significant barriers and solutions to implementing and maintaining GSI in Vermont municipalities. Additionally, urban and rural towns provide very different contexts for implementing and maintaining GSI in Vermont and characteristics of development patterns and maintenance capacity should be considered in policy, regulations, outreach, and education.

The third chapter offers a literature review, guided by a CES framework, of design elements that can be included in GSI to create multifunctional urban green spaces. CES categories of aesthetic, recreation, education, sense of place, social capital, and stewardship benefits framed a set of design elements, principles, practices, and documented benefits to guide multifunctional design of GSI. Findings include the importance of participatory processes to elicit diverse landscape values, visible water pathways, biodiversity, spaces for creative use, accessibility, interaction with water, interpretive signage, and artful and biophilic design features to enhance feelings of preference, pleasure, relaxation, learning, connection, and inclusion. The health and wellbeing of water and people must be integrated into the design of GSI for cities to be ecologically functional and culturally meaningful to their populations.

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CHAPTER 1: Literature Review

1.1 Introduction

This research explores the human side of green stormwater infrastructure (GSI), studying barriers and solutions to adopting and maintaining GSI in Vermont (USA) municipalities, and identifying multifunctional design elements that can enhance both biophysical and cultural ecosystem services (CES) in urban green spaces. The adaptation of conventional pipe-based "grey" stormwater infrastructure to include more plant and soil-based "green" stormwater infrastructure to capture and treat stormwater runoff and protect water quality offers an opportunity to integrate these living systems into the communities and cultures of Vermont and elsewhere. Effective maintenance and multifunctionality of GSI are hypothesized to be key ingredients for the long-term success of stormwater treatment systems and resulting water quality benefits. The overarching goal of this research is to aid the successful implementation and management of widespread green stormwater infrastructure (GSI) in built environments to be ecologically beneficial, municipally managed, and culturally valuable.

Research goals include characterizing the current state of GSI adoption and aesthetic preferences according to municipal officials, identifying operational and perceptions of maintenance capacity for GSI, and eliciting lessons that can inform effective GSI practices and policies for Vermont municipalities and elsewhere. CES as a framework to guide multifunctional design solutions for GSI is proposed as a critical lens for project success to provide both biophysical and cultural services. Multifunctional design elements are based on documented benefits to human health and wellbeing and aim to reconnect urban-dwellers with vital ecological processes through aesthetically pleasing, interactive, accessible, educational, and place-based design for GSI.

This research employs survey methods to explore barriers to adopt and maintain GSI on the municipal level and literature review methods to investigate cultural benefits that can be enhanced through design principles and practices. Research questions are based on the premise that ecological functions of built environments are mediated through social, cultural, economic, and political processes and therefore, those processes must be central to GSI solutions.

The following sections provide background information on topics related to this research study. The issues surrounding stormwater runoff (1.2) are explained and GSI (1.3) is introduced as a solution. The history of urban green space (1.4) is illustrated to provide context for the evolution of GSI and the places it is most often adapted for. The concept of CES (1.5) is presented as an effective theoretical framework for multifunctional design. Landscape visualizations (1.6) are introduced as a method to communicate complex landscape changes and to elicit perspectives of stakeholders and aid in participatory planning. Finally, participatory action research (PAR) (1.7) is suggested as a theoretical and action-oriented basis for carrying out participatory processes. These threads will weave throughout Chapters 2 and 3, providing the justification, methods, and theoretical framework for this research.

1.2 Stormwater Runoff: Causes and Effects

Natural ecosystems provide many functions and ecological services, including the regulation of hydrologic flows through rainfall infiltration and evapotranspiration, water filtration, groundwater recharge and storage, flood prevention and clean drinking water (Rudolf S de Groot, Wilson, & Boumans, 2002; US EPA, 2013). These natural processes allow precipitation in the form of rainfall and snowmelt, to be slowed, captured, and naturally filtered before entering receiving water bodies. Development alters the natural landscape and causes increased soil compaction and impervious surface area, and decreased plant diversity and vegetative cover, replacing natural ecosystems and their ability to treat stormwater (Booth & Jackson, 1997; US EPA, 2013).

Stormwater runoff refers to the rainfall and snowmelt that does not infiltrate, evapotranspire, or sublimate, and washes off our roofs, driveways, parking lots, roads, and lawns and continues to be a leading cause of impairments in the nation's waterways due to an increase of impervious surfaces (Booth & Jackson, 1997; Dietz & Clausen, 2008; US EPA, 2002). Urban and suburban development and the resulting impervious surfaces are key contributors to deteriorating water quality in streams, rivers, and lakes and collapse of freshwater ecosystems in the United States due to increased stormwater runoff rates and volumes and decreased infiltration, groundwater recharge and baseflow in streams (Ahiablame, Engel, & Chaubey, 2012; Booth & Jackson, 1997; Carle, Halpin, & Stow, 2005; Dietz & Clausen, 2008; Jennings & Jarnagin, 2002; Line & White, 2007; Roy, Rosemond, Paul, Leigh, & Wallace, 2003; US EPA, 2013).

Increased stormwater runoff rates and volumes creates frequent flooding problems and yield greater quantities of sediment, nutrients (e.g., phosphorus and nitrogen), and other pollutants (e.g., heavy metals, road salt, oil and grease, pesticides and herbicides, organic matter) from impervious surfaces, farm fields, residential lawns, and commercial and industrial properties, and depositing them into receiving water bodies

(Line & White, 2007; Steinman, Isely, & Thompson, 2015). Line and White (2007) found that phosphorus and nitrogen exports from a residential development in North Carolina was 66 to 88% greater than a forested and agricultural area, and sediment export was 95% greater for the developed area. Stormwater runoff carrying pollutants can load waterways with sediment and nutrients, causing sedimentation and eutrophication in freshwater bodies, which stimulates cyanobacteria growth (blue-green algal blooms), leading to hypoxia or anoxia (deficiency of oxygen), killing aquatic species and creating public health risks (Correll, 1998; Kotak, Lam, Prepas, & Hrudey, 2000; Roy et al., 2003; Schindler et al., 2008; Steinman et al., 2015). These toxic algal blooms cause a loss of biodiversity in aquatic ecosystems and impair water for drinking, industry, agriculture, recreation, and indirect impacts on the economy such as decreased property values (Carpenter et al., 1998). In addition, stormwater-related impacts are expected to increase with climate change due to increasing precipitation events in the northeast, especially severe precipitation events, resulting in more flooding (Betts, 2011; Frumhoff, McCarthy, Melillo, Moser, & Wuebbles, 2007; Galford et al., 2014; Steinman et al., 2015).

Conventional stormwater management prioritizes expedient removal of stormwater to protect human health and property without consideration for the environmental consequences (Booth & Jackson, 1997; Roy et al., 2008). Conventional "grey" stormwater systems use grates, basins, drains, pipes, channels, and sewers to quickly convey stormwater to receiving water bodies, typically untreated (Farrelly & Brown, 2011; Rowe, Rector, & Bakacs, 2016). Many developed towns and cities have combined sewer outflows (CSOs) that integrate stormwater runoff into wastewater, increasing costs of wastewater treatment facilities and causing overflows of raw sewage to waterways in flooding events (Roy et al., 2008). Heavy runoff associated with severe precipitation events will increase risk of sewage overflows, known as combined sewer overflows (CSOs), contaminating local waters, and increasing the risk of human illnesses (Steinman et al., 2015). The unintended environmental consequences of degraded aquatic ecosystems and water quality are now threatening human health and property (Steinman et al., 2015).

1.3 Green Stormwater Infrastructure

Green stormwater infrastructure (GSI) offers decentralized stormwater management tools that mimic hydrologic flows of a pre-development landscape and reduce transport of pollutants downstream, offsetting the harmful impacts of impervious cover (Dietz, 2007; Roy et al., 2008). GSI utilizes the storage, infiltration, evapotranspiration, and filtration capacities of gravity, earthworks, structural features, plants, and soils (W F Hunt et al., 2010). Low impact development (LID) and water sensitive urban design (WSUD) are similar approaches to stormwater management that aim to restore hydrologic processes to pre-development conditions and often use GSI practices to achieve those goals (Ahiablame et al., 2012; Roy et al., 2008). GSI uses vegetation and soil media to retain and store runoff, increase percolation and infiltration rates, recharge groundwater, promote evapotranspiration, water re-use, and reduce pollutant loads by way of filtration, chemical sorption, phytoremediation, and biological processes (Ahiablame et al., 2012; Hunt et al., 2010). Common GSI practices include: bioretention/raingardens, dry wells, bioswales, green roofs, porous/permeable pavers, street tree cells, stormwater ponds, and rain barrels (Ahiablame et al., 2012; Hunt et al., 2010; VTDEC, 2017).

Reduced runoff volumes and pollutant load removal rates vary among GSI practices; bioretention and other variations, such as raingardens, infiltration swales, and stormwater planters, characterized by added infiltration soil media, are the most studied and well-understood practices and are often credited as the best management practice for reducing sediment and nutrient losses (Ahiablame et al., 2012; Davis, Hunt, Traver, & Clar, 2009; Dietz & Clausen, 2008; Hunt et al., 2010; Hunt & Lord, 2006; Roy-Poirier, Champagne, & Filion, 2010). Pollutants that have been documented to be removed via bioretention with a wide variation of success include sediments or total suspended solids (TSS), nutrients of primary concern including phosphorus and nitrogen, heavy metals, and bacteria from organic waste (Ahiablame et al., 2012; Davis et al., 2009; Kratky et al., 2017). Reduction of runoff volume and peak flow rates using bioretention is significant and well-documented (Ahiablame et al., 2012; Davis et al., 2009; Kratky et al., 2017).

Mimicking natural hydrological patterns can help enhance landscape resilience (Foster, Lowe, & Winkelman, 2011; Matthews, Lo, & Byrne, 2015) in the face of increasing severe precipitation events in the northeast (Betts, 2011; Frumhoff et al., 2007), alleviate the impacts of urban and suburban development and expansion of impervious surfaces (Dietz & Clausen, 2008), and help amend the threats to human health and wellbeing due to degraded urban environments and water sources (Bolund & Hunhammar, 1999; Steinman et al., 2015). GSI practices have shown to be successful at reducing pollutant loads (Ahiablame et al., 2012; Kratky et al., 2017), cost-effective (Dietz, 2007; Houle, Roseen, Ballestero, Puls, & Sherrard, 2013; US EPA, 2007, 2013), and provide multiple ecological and cultural co-benefits (Andersson et al., 2014; Ando & Netusil, 2018; Echols & Pennypacker, 2008; Meerow & Newell, 2017). While solving problems related to stormwater, GSI creates solutions to provide multiple ecological and cultural benefits, including biodiversity and improved access to green space (Rowe et al., 2016).

1.4 Cultural Ecosystem Services

People have been studying and characterizing the deep and dynamic connections between human beings and ecosystems for centuries, and probably ever since humans were first conscious of their connection with and reliance on ecosystems, and later, their widespread impact upon ecosystems (Fisher, Turner, & Morling, 2009; Gould et al., 2015; Marsh, 1864; Schama, 1995). Ecosystem services (ES) is a conceptual framework to identify and provide value for the benefits that human populations derive, directly or indirectly, from ecosystem functioning (Bolund & Hunhammar, 1999; Costanza et al., 1997; de Groot et al., 2002). ES were first introduced in 1977 as ‘nature’s services’ to bring greater value to natural resources and make more informed policy and management decisions based on the benefit of natural resources to human wellbeing (Ernstson & Sörlin, 2013; Westman, 1977). They were coined ‘ecosystem services’(Ehrlich & Ehrlich, 1981), formalized with a written history (G. E. Daily, 1997), and then widely popularized and applied by the Millennium Ecosystem Assessment (MA) called for by UN Secretary-General Kofi Annan in 2000 (Fisher et al., 2009; MEA, 2005). The MA assessed the consequences of changing ecosystems due to human impact and how it would, in turn, impact human well-being and the services ecosystems provide including: supporting (e.g., habitat, genepool), regulating (e.g., climate, air quality, soil formation), provisioning (e.g., clean water, food, fuel), and cultural (e.g., recreation, aesthetic, inspiration) services (de Groot, Alkemade, Braat, Hein, & Willemen, 2010; MEA, 2005).

Since the late 1990s, there has been a gradual shift from describing ES in terms of metaphorical value to an operationalized framework that uses quantification and economic valuation as its standard practice to essentially put a price on nature, which is presented as a science-based development (Ernstson & Sörlin, 2013). The Economics of Ecosystems and Biodoversity (TEEB) Manual has attempted to scale ES and to provide a method to catalog, quantify, and put a price on certain aspects of urban nature to be applied objectively anywhere in the world (Kumar, 2012). Ernstson (2013) argues that ES cannot exist "out there" as objective, measurable and comparable elements, but must rather be considered as knowledge and viewpoints that are embedded in in social and cultural processes. This view of ES as perceptions situated in social and political processes yields more diverse views and valuations and recognizes that the process of giving value to ES is a largely social, cultural, and political process, not an objective economic process.

There has been extensive research on the biophysical services (e.g., supporting, regulating, provisioning), but not as much consideration on the nonmaterial or cultural benefits of ecosystem services (Gould & Lincoln, 2017). Cultural Ecosystem Services (CES) have multiple definitions; this research is based on a widely-used definition of CES as the "nonmaterial benefits (e.g., capabilities and experiences) that arise from human-ecosystem relationships" (Chan, Satterfield, & Goldstein, 2012, p. 9). An additional definition from Russell et al. (2013, p. 475) helps to clarify and nest CES in complex socio-cultural processes, defining CES as “ecosystem contributions to human well-being mediated through nonmaterial processes (e.g. the mind or culture).” There exist over a dozen typologies of CES, developed over the last decade by scholars to help organize and categorize the “body of experience and benefits” included in the CES concept (Gould & Lincoln, 2017, p. 117). Defining CES categories explicitly is challenging due to the complexity, interdependence, intangibility, nuance, and abstract concepts that require myriad research methods and are difficult to articulate and quantify (Chan et al., 2012; Gould & Lincoln, 2017). There are four categories of CES that are widely agreed upon and provide a core of benefits, including recreation, spirituality, aesthetic, and artistic (Gould & Lincoln, 2017). Other CES categories identified by researchers include cultural heritage, education, social capital/relations, sense of place, existence, knowledge systems, cultural diversity, identity, bequest, ingenuity, perspective, and life teaching (Gould & Lincoln, 2017; Milcu, Hanspach, Abson, & Fischer, 2013; de Groot, van de Berg, & Amelung, 2005). The multitude of classifications within the body of experience and meaning that ecosystems provide for human culture and well-being point to the diverse benefits that humans receive from the landscape. Benefits range from physical health to knowledge of one’s place within the natural processes of the landscape, from a sense of connection to a larger system to sources of beauty and new ways of seeing and creating in the world (Gould et al., 2014; Gould & Lincoln, 2017).

There are many challenges to integrating the concept of ES into management, land planning, and decision-making due to dynamic valuations (de Groot et al., 2010;

Fisher et al., 2009). De Groot et al. (2010) state that the main challenge of integrating ES into landscape planning is deciding on optimal allocation and management of the many land uses available and the ecosystem services required and desired. It is important to evaluate and visualize the services of a land use, not only the land use itself, to integrate an 'ecological service approach' to land planning and management (de Groot et al., 2010). Furthermore, the cultural nonmaterial elements of human-ecological relations are even harder to articulate and evaluate than biophysical elements, often excluding them from economic valuation and making it difficult to include these vital and invaluable considerations into decision-making (Chan et al., 2012; Gould et al., 2015). The challenge arises because CES cannot often be compared or monetized and do not fit into the ES cost-benefit or risk assessment analytical frameworks; CES are incommensurable (Chan et al., 2012). The ES approach must include CES in decision-making for it to be a viable approach to land planning.

Cultural ecosystem services must be considered fully and justly, not only as "an after-thought or poorly represented by ill-suited value metrics." (Chan et al., 2012, p. 9). There is a call in the literature for the use of diverse social-science valuation tools and methods in addition to economic ones, including deliberative democratic approaches, a multi-metric performance measure of community support, and greater characterization and dynamic visualization of CES to provide alternative modes of valuation (Chan et al., 2012; de Groot, 2010). Chan et al., (2012, p. 8) call for a broader consideration of cultural values that will include diverse perspectives of value to "better integrate a broader set of social perspectives and valuation techniques into the ecosystem services framework, to enable a fuller characterization and representation of diverse ecosystem values in research and practice, while being mindful of the challenges of doing so." As with many issues in ES and CES, there are 'geographies of difference,' where some populations have more access to this value articulation, such as mapping, scientific reports, and access to information and historical data, which greatly impacts their ability to articulate value for places they fight to protect and create (Ernstson, 2013).

The more depth and clarity that can be used to describe CES, the more emotive responses will arise, with a goal of motivating action to protect and improve ecosystems, and ultimately, support the web of nature that human existence depends upon. Finding more diverse and creatively representative expressions of CES valuations will help to improve the problem of CES being largely forgotten in decision-making or "dismissed as hidden externalities" (Chan et al., 2012). Gould and Lincoln (2017, p. 123) express this issue clearly, "when we name phenomena they become more comprehensible to us, and when phenomena are more salient to us we name them." Therefore, characterizing CES is a social practice of value articulation, rooted in history and moderated by social and political processes (Ernstson, 2013; Ernstson & Sorlin, 2013). Valuing CES often leads to creating or protecting ecosystems and the services and benefits they provide; e.g., old artifacts (maps, paintings) are curated to help build a narrative about an urban green space in Stockholm that is named EcoPark and given value and saved from development (Ernstson & Sörlin, 2013); the historical pastoral vernacular of a rural landscape inspires neighbors to maintain a stone wall and open hay fields to preserve identity and sense of place (Morse et al., 2014); writings and paintings about the emotional and psychological importance of pristine 'wilderness' help instill Americans' cultural attachment to wildlands and moral duty to create the U.S. National Parks (Hartig et al., 2011).

These actions to protect and enhance ecosystem functions are part of the reciprocal flow of services from humans to ecosystems. What Comberti et al. (2015) describe as ‘services to ecosystems’ (S2E) are the “actions humans have taken in the past and currently that modify ecosystems to enhance the quality or quantity of the services they provide, whilst maintaining the general health of the cognized ecosystem over time” (p. 247). This alternative framework, which builds upon the ES framework and conceptualizes the relationship as a reciprocal loop, emphasizes the inclusion of maintenance and enhancement of ecosystems in management strategies based on ES, and the importance of ethnographic research in ES-based interventions (Comberti, Thornton, Wyllie de Echeverria, & Patterson, 2015).

S2E are a result of preferences, principles, and virtues arising from responsibilities felt as a steward, appropriateness for time and place, and the seeking of balance between human and nature for an individual and society (Chan et al., 2016). New ways of seeing ecosystems and valuing them can change with new questions and framing that aim to come more into balance with a “good” relationship (Chan et al., 2016). Human actions and impacts on ecosystems can have positive or negative effects on ecological functioning (Gobster et al., 2007). Planning, management, and design fields often mediate S2E and provide the processes to more fully realize the diversity of ecosystem values at hand, given a more inclusive framework and guiding principles, to consider the full range of ES (including CES) at stake.

1.5 Urban Green Space: History & Design

The fields of landscape architecture and landscape design have been considering the needs of both people and ecology from their inception, and benefit from the well-researched conceptual and theoretical framework of cultural ecosystem services (Andersson, Tengö, McPhearson, & Kremer, 2015; Meerow & Newell, 2017). A continuum between artful 'iconic' landscapes and ecologically functional landscapes characterizes the field of landscape architecture, and for the success of the field and the built environment itself, ecological landscape must become iconic, merging art and ecology (Mozingo, 1997). GSI provides the perfect opportunity to enhance the ecological function of streetscapes and built environments everywhere, while also being artful and culturally significant.

The field of landscape architecture evolved from a reaction to the "cramped horizontal gridiron of a town…hidebound in its deadly uniformity of mean ugliness," as expressed by Edith Wharton, a writer and designer, in her memories of New York City as a child (Blodgett, 1976; Botkin & Beveridge, 1997). Frederick Law Olmsted, often considered the father of landscape architecture, wrote extensively about humans' innate need for natural spaces, and his efforts led to some of the earliest urban parks in the late 19th century, including Central Park in New York City and the Emerald Necklace in Boston. Olmsted "wrote at length about the therapeutic value of the urban park in offering escape from the stacked compactions of the commercial city" and that a "frequent release from urban tensions was vital to all urban classes" (Blodgett, 1976, p. 878). Olmsted expressed biophysical ecosystem services of urban green spaces, describing urban parks as the lungs of the city with their clean air and breezes, away from harmful air pollution of early industrial cities. He also expressed cultural ecosystem services in his hope for parks to inspire communal feelings and increase 'communicativeness' among all socioeconomic classes (Blodgett, 1976, p. 878). Early urban parks introduced ideas of ecological function and the health and wellbeing benefits of natural spaces in cities, but they were still largely socially and not ecologically driven, characterized by wide expanses of manicured lawns, which are deplete of biodiversity and ecologically harmful (Cranz & Boland, 2004).

Urban areas must be designed to simultaneously meet sociocultural and ecological goals, where cities are seen as part of nature and capable of significant ecological services in addition to minimizing harmful impacts to surrounding ecosystems (Cranz & Boland, 2004; Mozingo, 1997; Spirn, 1980). Multifunctionality is at the heart of designing urban green spaces for all ES; in order to provide biophysical ES in highly valued spaces that compete with other land uses that may provide more immediate and tangible economic benefits, "we need heterogeneous, multifunctional and accessible blue and green infrastructure throughout our cities" that build upon highly valued CES (Andersson et al., 2015, p. 165). The need to design functional and artful spaces has become clear, characterized by the need to improve the impact of built environments on the health of inhabitants and the surrounding landscape (Nassauer, 2011). The biophilia hypothesis and related studies on humans' physiological and psychological need to interact with natural elements have shown that and we are evolved to find beauty and refuge in living systems (Gillis & Gatersleben, 2015; Heerwagen, 2009; Kellert & Calabrese, 2015; Kellert & Wilson, 1993; Wilson, 1984). However, studies have shown that what is seen as aesthetically pleasing is not always of ecological quality and what is ecologically healthy is not always considered beautiful (Gobster, 1994b; Gobster et al., 2007; Mozingo, 1997; Nassauer, 1995). This ‘scenic’ or ‘picturesque’ aesthetic, the pleasurable response that humans have to natural-appearing scenery is an evolutionary tendency to perceive landscapes with positive aesthetic experiences as tied to positive ecological quality, ecological quality, even when many viewers do not have the tools to judge ecological quality (Gobster et al., 2007).

Perceptions and acceptance of landscapes are psychological and tied to deeply rooted cultural values. Currently, landscape designs that support ecological functions can often be overlooked or misunderstood and there is even evidence of significant negative public reaction to ecologically valuable landscapes (Gobster, 1994a; Gobster et al., 2007; Kaplan & Kaplan, 1989; Mozingo, 1997; Nassauer, 1995). For example, many studies have found that more naturalistic plantings found in native ecological communities are perceived as “messy,” “dirty,” and “hard to play in” by inner-city kids (Gobster, 1992) or “unkempt” and “overgrown” by those who did not have special interest or knowledge in ecology or native plants (Schulhof, 1989). In American society, ecological diversity can sometimes be seen as “messy” or neglected and reflective of poor social values (Nassauer, 1995). American culture views neat and orderly landscapes as reflective of good neighborliness, hard work, and pride (Nassauer, 1988, 1993). Nassauer explains, “novel landscape designs that improve ecological quality may not be appreciated or maintained if recognizable landscape language that communicates human intention is not part of the landscape” (1995, p. 161). Nassauer (1995) found that “cues to care”, design cues signifying human intention, are an effective method to adapt cultural expectations to recognize new biodiverse landscape uses that provide more ecosystem services. Bringing the natural structures and functions into familiar patterns can both physically and culturally nest designs in the larger ecological processes and cultural patterns of the landscape. These cues to care speak to the concept of ‘eco-revelatory design’, previously called ‘visual ecology’, or making ecology more visible to the viewer and their dependence on ecosystem functioning more evident (Thayer, 1976, 1998; van Bohemen, 2002).

The future of urban green spaces is ecologically and socially driven design integrated into buildings, streetscapes, and parks to provide the full range of biophysical and cultural ecosystem services. The fields of landscape architecture and design have an opportunity to play an important role in creating ecologically beneficial and aesthetically pleasing urban environments and GSI offers many tools to achieve these goals. As Olmsted wrote of the social necessity and preservation of American values in urban parks (Blodgett, 1976) and Thoreau wrote of the moral obligation to protect the wilderness areas that became the U.S. National Parks (Cronon, 1996), urban areas become the nexus of humans’ inseparable relationship with nature and whether it is one of mutualism or parasitism.

1.6 Landscape Visualizations

Visual communication has a long history in environmental planning, especially landscape planning and architecture (Lange, 2011; Zube, Simcox, & Law, 1987). Visual imagery can cause cognitive (i.e., understanding), affective (i.e., emotions), and behavioral (i.e., decision-making) responses in people (Sheppard, 2005). Visual imagery has been shown to improve understanding and even influence people's decision-making (Sheppard, 2005; Slovic, Finucane, Peters, & MacGregor, 2002). Realistic visual imagery representing current and future environments, called landscape visualizations, are now often computer-generated and can show detailed information with high realism and validity (Sheppard, 2005; Zube et al., 1987). Landscape visualizations have been found to be accessible to diverse audiences to engage public participation planning and influence decision-making through increased understanding and communication between different disciplines and stakeholders (Al-Kodmany, 2002; Lewis & Sheppard, 2006; Meitner et al., 2005; Tress & Tress, 2003).

The cognitive advantages of visual imagery over written and verbal information is well known, and benefits of using landscape visualizations in the public realm to aid understanding and decision-making is generally agreed upon (Lewis & Sheppard, 2006; Nørretranders, 1991; Schattman, Hurley, & Caswell, 2018; Tufte, 1983). Realistic landscape visualizations have been found to be one of the most effective ways to help people imagine future scenarios (Sheppard, 2012), and have been used in numerous studies to elucidate preferences for land use and restoration (Bettigole, Donovan, Manning, & Austin, 2014; Junker & Buchecker, 2008), agricultural practices (Schattman et al., 2018; Wilhelm, 2014), and aesthetic and conservation values (Lindemann-Matthies, Briegel, Schüpbach, & Junge, 2010; Lindemann-Matthies, Junge, & Matthies, 2010; Soliva & Hunziker, 2009). Visualizations are key for engaging local stakeholders and building participatory capacity as an approach for sustainable development at the local level, especially when the visuals are credible and easily accessible in a local context and at a scale that matters to people (Shaw et al., 2009; Sheppard et al., 2011; Tress & Tress, 2003).

Visualizing alternative future scenarios in the landscape has proven to be extraordinarily effective at encouraging active stakeholder participation (Sheppard, 2005; Warren-Kretzschmar & Tiedtke, 2005). Using images to envision planning decisions enhances citizen connection to community planning and encourages participation from the public (Sheppard, 2012). Photo-simulations and other landscape visualizations can help laypersons understand spatial and temporal processes of planning proposals in the landscape and prompt conversation and interest among stakeholders (Warren-Kretzschmar & Tiedtke, 2005). It has been found that when landscape visualizations of design proposals include sufficient detail of features previously considered controversial or unacceptable, people were more likely to change their opinions to accept these proposals (Barbarash, 2008; Neto, 2006). Landscape visualizations can be used to facilitate increased understanding of spatial components, aesthetics, and ecological attributes of proposed GSI practices. These images can increase understanding and help support dialogue and decision-making among planners, designers, property owners, community members, and other stakeholders.

1.7 Participatory Action Research

Public participation is an invaluable component of successful landscape planning and it is vital to include community stakeholders in the decision-making process (Warren-Kretzschmar & Tiedtke, 2005). Participatory Action Research (PAR) is an approach to research, which can be applied to planning, that “involves researchers and participants working together to examine a problematic situation or action to change it for the better" (Kindon, Pain, & Kesby, 2007). Participatory approaches to research emerged to challenge the traditional hierarchy and power relations between researchers and the 'researched', to bring forward the expertise of non-researchers, and to directly benefit communities involved in research (Kindon et al., 2007). PAR is a collaborative approach where typically non-researchers are involved as co-researchers and decision-makers to democratize the process and break down hierarchical roles and power dynamics to make way for a flexible and socially-owned research process (Cahill, 2007; Kindon et al., 2007). The goal is an iterative process that fosters collaborative and co-creative knowledge from the outset of the project to create actionable solutions (Méndez, Caswell, Gliessman, & Cohen, 2017).

PAR follows iterative cycles of 'preflection' (preliminary reflection or forethought), research, reflection and action that are nonlinear, context-specific, emergent, reliant on flexible and complex thinking, and are often very 'messy' (Mendez et al., 2017). Reflection and sharing are key throughout the entire process to identify emergent themes and maintain transparency between all actors to minimize the occurrence of traditional power relations. PAR is a transformational process that requires negotiation, flexibility, accountability, patience, long-term commitment, shared interest and belief in collective power, humility, trust, and communication (Mendez et al., 2017).

PAR provides an approach to elicit diverse cultural values of urban green spaces and designing GSI for multifunctional uses that is based on mutual values (Kati & Jari, 2016; Maraja, Barkmann, & Tscharntke, 2016). A goal of participatory planning is to think with the community, not for the community, in the initial stages of a project and provide an environment that is conducive to knowledge sharing and encourages open dialogue through unconstrained and interactive conversations (Mendez et al., 2017). Approaches that encourage participation and collaboration include the World Café approach (Preller, Affolderbach, Schulz, Fastenrath, & Braun, 2017), landscape visualizations of future scenarios (Tress & Tress, 2003), and participatory scenario planning (PSP) (Oteros-Rozas et al., 2015), which all include the use of visuals or models to engage participants and support an open discussion. If possible, tools used to communicate ideas should span learning styles, languages, and knowledge systems, such as landscape visualizations, drawings, illustrations, PSP modeling, collage, and value mapping to identify mutual values (Fox, 2006; Kati & Jari, 2016). Creating space for active participation and experimentation by citizens can allow for emergent ideas to arise (Bendt, Barthel, & Colding, 2013).

Urban green spaces and the benefits they provide are not equitably distributed across urban populations, based on socioeconomic determinants (Jennings, Larson, & Yun, 2016). In creating and enhancing urban green spaces, it is important to site GSI in locations where ES and CES are lacking most, typically dense and poor urban areas to ameliorate the impacts of social inequality (Dunn, 2010).

1.8 Conclusion

Stormwater runoff is a complex problem embedded in a landscape that is mediated by social, cultural, political, and economic processes; solutions require creative and diverse methods. GSI practices and technologies provide the tools to manage stormwater on a biogeochemical level. CES and knowledge of human preference and benefits to health and wellbeing provide the context for well-received design. Landscape visualizations and participatory processes provide the methods to help elucidate diverse values and ways of knowing in the planning, implementation, operation, and maintenance of multifunctional GSI.

1.9 References

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CHAPTER 2: MUNICIPAL GREEN STORMWATER INFRASTRUCTURE IN VERMONT: MAINTENANCE CAPACITIES, PERCEPTIONS OF MAINTAINABILITY, AND AESTHETIC PREFERENCES

Abstract

While green stormwater infrastructure (GSI) can help developed landscapes exhibit naturalistic hydrologic patterns, many municipalities struggle to integrate the design and maintenance of GSI into their communities and cultures. This study aims first to document what Vermont (USA) towns and cities already have in place for different types of stormwater management practices and, second, to address the operational barriers of GSI maintenance requirements by asking respondents about specific maintenance practices. Third, this research aims to address behavioral and cultural barriers to adopting and maintaining GSI by examining municipal officials' perspectives on visual appeal and maintainability of different design scenarios for a common GSI practice, bioretention. A number of different town attributes were then explored as independent variables potentially related to perceptions of GSI.

An online survey was sent to municipal officials in Vermont by the NSF-EPSCoR-funded Basin Resilience to Extreme Events (BREE) research team and administered by the Castleton Polling Institute in Summer and Fall of 2017. In addition to demographic questions and an assessment of the current state of GSI practices and maintenance activities, the survey used landscape visualizations, placed in the backdrop of a typical downtown Vermont street right-of-way, to communicate possible design scenarios including "grey" storm sewer infrastructure and three "green" vegetated bioretention designs to elicit municipal officials' aesthetic and functional preferences.

Key findings include the positive impact of stormwater policies on both diversity of GSI practices in place and positive views of town maintenance capacity for vegetated bioretention designs. Visual appeal and perceived maintainability of vegetated bioretention practices do not appear to be significant barriers to adoption and operation, but policy and funding are shown to be both significant barriers and solutions to implementing and maintaining successful GSI in Vermont communities. Additionally, urban and rural towns provide very different contexts for implementing and maintaining GSI in Vermont and characteristics of development patterns and maintenance capacity should be considered in policy, regulations, outreach, and education.

2.1 Intro

2.1.1 Stormwater

Natural ecosystems provide many functions and ecological services, including the regulation of hydrologic flows through rainfall infiltration and evapotranspiration, water filtration, groundwater recharge and storage, flood prevention and clean drinking water (de Groot et al., 2002; US EPA, 2013). These natural processes allow precipitation in the form of rainfall and snowmelt to be slowed, captured, and naturally filtered before entering receiving water bodies. Development and urbanization alter the natural landscape by increasing soil compaction and impervious surface area, and decreasing plant diversity and vegetative cover; this diminishes the ability of natural ecosystems to absorb runoff (Booth & Jackson, 1997; US EPA, 2013).

Stormwater runoff refers to the rainfall and snowmelt that does not infiltrate, evapotranspire, or sublimate, but instead washes off roofs, roads, parking lots, driveways, and lawns (Booth & Jackson, 1997; Dietz & Clausen, 2008). Alteration of natural hydrological systems by development—and its proliferation of impervious surfaces—leads to increased stormwater runoff rates and volumes (Jennings & Jarnagin, 2002), decreased infiltration, decrease in groundwater recharge and baseflow (Line & White, 2007), and deterioration of water quality in streams, rivers, and lakes (Carle et al., 2005; Roy et al., 2003; Schueler et al., 2009). Stormwater runoff is a key contributor to degraded water quality and collapse of freshwater ecosystems in the United States (Ahiablame et al., 2012; Booth & Jackson, 1997; Dietz & Clausen, 2008; US EPA, 2013).

Development causes changes to natural hydrology, altering flow regimes, stream morphology, temperature, water chemistry, habitat diversity, nutrient cycling, and other ecosystem processes that are closely tied to stormwater discharge (Konrad & Booth, 2005; Roy et al., 2008). In fact, impervious cover and stream water quality are so interrelated that stream water quality, as measured by biota in waterways (Roy, Rosemond, Paul, Leigh, & Wallace, 2003), channel morphology changes (Booth, Hartley, & Jackson, 2002), and decreased baseflow in streams (Line & White, 2007; Wang, Lyons, Kanehl, & Bannerman, 2001), can be predicted from the percent of impervious cover in its watershed (Dietz & Clausen, 2008; Schueler et al., 2009). At an average of just 7% impervious cover (range 2-15%), stream degradation is first detected at about 20-25% impervious cover, many stream indicators shifted to a poor condition (Schueler et al., 2009). Generally, watersheds with impervious surfaces greater than 10% of the landscape are considered to be impaired (Dietz & Clausen, 2008; Steinman et al., 2015; Wang et al., 2001).

Unmanaged stormwater runoff causes erosion of stream banks and shorelines as well as flooding (Booth et al., 2002; Konrad & Booth, 2005; Schueler et al., 2009). Stormwater contains sediment, nutrients (i.e., phosphorus and nitrogen), and other pollutants (e.g., heavy metals, road salt, oil and grease, pesticides and herbicides, fertilizers, organic matter) which are deposited into receiving water bodies (Line & White, 2007; Steinman et al., 2015). Pollution caused by stormwater runoff can load waterways with nutrients, which stimulates algae blooms, leading to fish kills and loss of species diversity, and public health risks (Roy et al., 2003; Steinman et al., 2015). In addition, stormwater-related impacts are expected to increase in some locations with climate change; projections suggest an increase in extreme precipitation events in the northeast (Betts, 2011; Frumhoff et al., 2007; Galford et al., 2014; Steinman et al., 2015).

Conventional stormwater management prioritizes expedient removal of stormwater to protect human health and property (Booth & Jackson, 1997; Roy et al., 2008). Conventional "grey" stormwater systems use grates, basins, drains, pipes, channels, and sewers to quickly convey stormwater to receiving water bodies, untreated, or to be treated with sewage in wastewater treatment facilities (Farrelly & Brown, 2011; Rowe, Rector, & Bakacs, 2016), where risk of combined sewer overflows can be exacerbated during heavy precipitation events. Ironically, the unintended environmental consequences of stormwater degrading aquatic ecosystems and water quality now threaten human health and property (Carpenter et al., 1998; Falconer, 1999; Gaffield, Goo, Richards, & Jackson, 2003; Steinman et al., 2015).

2.1.2 Green Stormwater Infrastructure

Green stormwater infrastructure (GSI) is a suite of structural stormwater management tools that aim to mimic hydrologic flows of a pre-development landscape, utilizing the storage, infiltration, evapotranspiration, and filtration capacities of gravity, earthworks, structural features, plants, and soils to offset the harmful impacts of impervious cover (Roy et al., 2008). GSI uses vegetation and soil media to retain and store runoff, increase percolation and infiltration rates, recharge groundwater, promote evapotranspiration, reuse water, and to reduce pollutant loads by way of filtration, chemical sorption, phytoremediation, and biological processes (Ahiablame, Engel, & Chaubey, 2012; Hunt et al., 2010; Roy et al., 2008). Common GSI practices include:

bioretention/raingardens, dry wells, bioswales, green roofs, porous/permeable pavers, street tree cells, stormwater ponds, and rain barrels.

Shaping the built environment to mimic natural hydrological patterns can help enhance landscape resilience (Foster, Lowe, & Winkelman, 2011; Gill, Handley, Ennos, & Pauleit, 2007), alleviate the impacts of urban and suburban development and expansion of impervious surfaces (Dietz & Clausen, 2008), and help amend the threats to human health and wellbeing due to degraded urban environments and water sources (Bolund & Hunhammar, 1999; Steinman et al., 2015). GSI practices have shown to be successful at reducing pollutant loads (Ahiablame et al., 2012; Kratky et al., 2017), providing multiple ecological and sociocultural benefits (Andersson et al., 2014; Ando & Netusil, 2018; Meerow & Newell, 2017), and cost-effective (Dietz, 2007; Houle, Roseen, Ballestero, Puls, & Sherrard, 2013; US EPA, 2007, 2013).

2.1.3 Maintenance and Aesthetics as Key Barriers to GSI

GSI provides effective and economic solutions to stormwater management, but given the relatively new awareness and adoption of these practices by municipalities, there remain barriers to GSI implementation (Hurley & Stromberg, 2008; NYDEC, 2017; Rowe, Rector, & Bakacs, 2016; Roy et al., 2008; University of Wisconsin Sea Grant Institute, 2013; US EPA, 2013; Vail & Meyer, 2012). Prominent barriers to GSI that have been identified in the literature relate to public perception (e.g. lack of awareness or resistance to change), operation and maintenance challenges (e.g. lack of institutional capacity and minimal or ineffective inspection and enforcement procedures), insufficient knowledge and expertise (e.g. uncertainties in performance and cost, limited training opportunities), and lack of funding and legislative mandate (e.g. reliable revenue streams or effective market incentives) (American Rivers, 2016; Coleman, Hurley, Rizzo, Koliba, & Zia, 2018; Houle et al., 2013; Matthews et al., 2015; Rowe et al., 2016; Roy et al., 2008; Vail & Meyer, 2012).

This research examines two major barriers to GSI implementation: aesthetic concerns and maintenance issues (Houle et al., 2013; Roy et al., 2008). Based on a survey of municipal officials in Vermont, USA, we further examine GSI implementation in terms of institutional capacity, funding, education, awareness, and public perception that interrelate with these barriers.

Negative public perception and resistance to change often stem from limited experience with and understanding of GSI, resulting in a fear of failure and unattractiveness (Eadie, 2002; Mongard, 2002; Roy et al., 2008). Support for and resistance to GSI projects has been tied to previous experiences and perceptions; pilot projects sometimes fail due to the novelty of the systems, which create negative perceptions (UW Sea Grant Institute, 2013). Due to a lack of successful demonstration projects, risk aversion to innovative technologies often leads to public concerns of ineffectiveness of unattractiveness (Farrelly & Brown, 2011; Roy et al., 2008; UW Sea Grant Institute, 2013). Some have argued that GSI has a “messy” appearance, especially if poorly maintained, which undermines support for more GSI (Gardiner, 2006; Nassauer, 1995; Roy et al., 2008; UW Sea Grant Institute, 2013). Landscape designs that support ecological functions can often be overlooked or misunderstood; for some ecologically valuable landscapes there is evidence of significant negative public reaction to the landscapes when they appear to be unkempt (Gobster, 1994; Kaplan & Kaplan, 1989; Mozingo, 1997; Nassauer, 1995b).

The misunderstanding of proper inspection and maintenance requirements of GSI is a significant barrier to proper maintenance and success of GSI projects (Houle et al., 2013; B. Tharp & Schatz, 2017). Proper maintenance of GSI is essential for ongoing efficacy of systems and to maximize water quality and other ecological, social, and economic benefits (Houle et al., 2013; US EPA, 2013). Routine inspection includes evaluation of erosion, sediment and debris build up, clogged inlets and outlets, plant health and survival, subsurface pipes and catch basins, and structural integrity. Routine removal of sediment and debris (e.g. trash, organic matter), and clearing of pipe infrastructure is necessary to ensure continued infiltration capacity. Plant survival requires watering during establishment, weeding, pruning of woody species, and cutting back herbaceous perennials at the end of season (time of senescence) to avoid reintroducing nutrients in plant biomass and to invigorate root growth (American Rivers, 2016; Philadelphia Water Department, 2014; Seattle Public Utilities, 2009). It is evident that routine GSI maintenance is essential for optimizing performance and aesthetic appeal, to retain efficacy as stormwater storage and nutrient sinks in the landscape, and to garner public support (Philadelphia Water Department, 2014; Roy, 2017; University of Wisconsin Sea Grant Institute, 2013).

Maintenance is not always a priority due to a perceived lack of funding capacity or policies/regulations to encourage and enforce GSI maintenance (Rowe et al., 2016; Vail & Meyer, 2012). Project budgets often lack long-term GSI maintenance plans or assign maintenance responsibility to a municipal department without consultation and involvement in the design process (NYDEC, 2017; Roy et al., 2008). It is suggested that likely reasons for failed maintenance plans are unfamiliar processes and lack of necessary equipment and the personnel and organizational capacity to provide routine maintenance (Tharp & Schatz, 2017). Municipalities must adapt to provide new functions or expand existing programs in order to properly operate and maintain GSI (NYDEC, 2017).

U.S. cities such as Portland, Seattle, and Milwaukee have demonstrated that public engagement and awareness can lead to widespread support of GSI and that demonstration projects and media to increase public education and reduce skepticism are key (Hurley & Stromberg, 2008; Roy et al., 2008). When people see that GSI in the public realm can be a landscape amenity, most people are supportive (Eadie, 2002; Mongard, 2002), especially when they are shown to increase property values in an area (Brown & Clarke, 2007; Lloyd, Wong, & Chesterfield, 2002).

2.1.4 Landscape Visualizations for communication of design concepts

This research utilizes landscape visualizations of proposed GSI practices to help gauge aesthetic preferences and maintenance perceptions among Vermont municipal officials. Landscape visualizations can play a key role in helping communities to envision successful GSI projects, fostering public support and engagement. The most utilized and studied landscape visualization are photorealistic renderings, or photo-simulations, that use computer programs such as Adobe Photoshop to transform images of landscapes to create previously unimagined scenarios that are realistic and representative of design solutions (Appleton & Lovett, 2003; Lewis & Sheppard, 2006). Landscape visualizations have been found to be accessible to diverse audiences, to engage public participation in planning activities, and to influence decision-making processes through increased understanding and communication among different disciplines and stakeholders (Al-Kodmany, 2002; Lewis & Sheppard, 2006; Meitner et al., 2005; Tress & Tress, 2003). Visualizations can help build participatory capacity as an approach for sustainable development at the local level, especially when the visuals are credible and easily accessible in a local context and at a scale that matters to people (Shaw et al., 2009; Sheppard et al., 2011; Tress & Tress, 2003).

2.1.5 Study Site

The study site for this research is the State of Vermont, USA, a rural state with only eight cities and towns of populations greater than 10,000 and nineteen cities and towns with more than 5,000 people, with a total population of 625,741 people (U.S. Census Bureau, 2010). Vermont's land area is part of four major watersheds: the Lake Champlain basin, draining 48% of the state, the Connecticut River basin (41% of the state), the Lake Memphremagog drainage basin (0.05%), and the Hudson River basin (0.05%), each receiving waterbody has a different impairment status due to stormwater from development and agricultural runoff (VT DEC, 2018a, 2018c). Eutrophication driven blue-green algae blooms in Lake Champlain have received significant public attention, with decades of documentation of hypoxia and fish kills associated with the blooms (Fortin et al., 2015). GSI has increasingly been promoted as a solution to address stormwater problems in Vermont (VT DEC, 2017).

Several types of stormwater policy and planning mechanisms have the potential to affect municipalities in Vermont. Municipal Separate Storm Sewer System permits

(MS4) are required by the federal National Pollutant Discharge Elimination System (NPDES) Program for designated Urbanized Areas (population density of at least 1,000 people per square mile) or areas with significant water quality impacts mandate adherence to water quality (e.g. Total Maximum Daily Loads (TMDL)) and quantity (e.g. flow rates) goals for nearby impaired waters (Osherenko, 2013; US EPA, 2016b; VT DEC, 2018b). Stormwater bylaws and ordinances are pieces of municipal legislation passed or rules adopted as standards or regulations and vary significantly in content included, detail provided, and enforcement language used. However, these bylaws and ordinances generally aim to promote or require stormwater management practices in new developments and retrofits to improve water quality impacts on local waterways (VT League of Cities and Towns, 2014). Stormwater Master Plans (SWMPs) are comprehensive, preventative, and cost-effective municipal plans and documents that prioritize stormwater projects and establish timely strategic plans based on public input, data collection and analysis, mapping, and structural and nonstructural GSI practices to mitigate flooding, erosion, and pollution problems (VT DEC, 2018).

2.1.6 Research Objectives & Questions

This research was conducted using a survey instrument disseminated to municipal officials in Vermont who were likely to be involved with stormwater management efforts at some level, including decision-making, planning, or managing. This study aims first to document what Vermont towns and cities already have in place for different types of stormwater management practices and, second, to address the operational barriers of GSI maintenance requirements by asking respondents about specific maintenance practices.

Third, this research aims to address behavioral and cultural barriers to adopting and maintaining GSI by examining municipal officials' perspectives on visual appeal and maintainability of different design scenarios for a common GSI practice, bioretention. A number of different town attributes were then explored as independent variables potentially related to perceptions of GSI.

The specific research questions evaluated herein include:

1. Which GSI practices do Vermont towns already have in place and what types of practices do they intend to implement in the near future [GSI practice diversity]?
2. What are the current stormwater-related maintenance practices in Vermont towns, including access to equipment and sources of labor?
3. Based on landscape visualizations of conventional storm sewer infrastructure and three roadside bioretention design scenarios, what are Vermont municipal officials' (a) aesthetic preferences and (b) perceptions about ability of their towns to maintain GSI systems?
4. How do town attributes (population, population density, percent developed imperviousness, tax base, stormwater policies, past experience with consequences of Tropical Storm Irene (in 2011)) influence current GSI practice diversity and perceived maintenance capacity in Vermont towns?

2.2 Methods

An online survey (LimeSurvey) conducted by the Vermont NSF-EPSCoR-funded Basin Resilience to Extreme Events (BREE) research team and administered by the

Castleton Polling Institute was sent to municipal officials in the 245 Vermont towns that have municipal governments (ten Vermont towns do not have municipal governments, including buels, gores, and other unincorporated towns) in the Summer and Fall of 2017. IRB approval was granted on May 16th, 2017, Protocol Exemption Certification CHRBSS 17-0543. Data collection was closed at the end of November 2017. Survey questions asked respondents about (1) existing ("in effect") and future ("likely to implement") built stormwater management practices, (2) current stormwater practice maintenance activities, (3) maintenance capacity (equipment and sources of labor), and perceptions about (4) aesthetics and (5) ability to maintain roadside bioretention systems.

The survey contained sixty-four questions, including both quantitative and qualitative questions, pertaining to stormwater management. (See Full Survey in Appendix A). This research analyzed demographic questions #1-5 (town, primary role in government, perceived MS4 status, town drainage systems) and developed and analyzed questions #36-64, pertaining to stormwater practices, landscape visualizations, and maintenance practices.

2.2.1 Demographics

Demographic variables of town name and primary role in government of respondent were obtained from survey data. After the survey data were collected, a population variable was developed to characterize town size, grouping Vermont towns into rural, mid, and urban size towns based on population. Following the Vermont State Legislature definitions of rural and urban towns (VSA Title 24, Chapter 117, Item 25), "'rural town' means a town having, as at the date of the most recent U.S. Census, a population of less than 2,500 persons…or a town having 2,500 or more but less than 5,000 persons that has voted by Australian ballot to be considered a rural town." For this research, a Mid-size town was considered 2500-5000 residents and Urban >5000.

Roles in government were divided into three groups: "Town clerks, Treasurers, and Assistants" (n=61); "Managers and implementers," such as public works employees, road foremen, and town planners (n=101); and "Decision/policy-makers," such as selectboard, town/city council, and planning commission members (n=32) (See full list of roles in Appendix A). In cases where a respondent filled in the "Other" column with a closely related role (n=34), they were categorized with the appropriate group. These groups were created to analyze how a respondent's position of role (i.e., implementers versus policy-makers) may impact perceptions of maintainability and visual appeal of GSI. The category names and groupings were refined with expert advice from the Vermont League of Cities and Towns (Archer, 2018).

2.2.2 Stormwater Management Practices

The list of stormwater management practices included in the survey (Appendix A) was initially developed from the 2017 Vermont Stormwater Management Manual Rule and Design Guidance (VSMM) with additions and fine-tuning of terms based on several state and city stormwater management manuals from other states and municipalities (Dietz, 2007; Philadelphia Water Department, 2014; UW Sea Grant Institute, 2013; VT ANR, 2017). Although not categorized as such for survey respondents, the list included both conventional stormwater infrastructure practices (e.g. culverts, ditches, swales, and detention ponds) as well as GSI practices (e.g. bioretention, wetlands, porous pavement, and green roofs).

A GSI practice diversity score was developed to create a variable representing the variety of green infrastructure practices reported to be in effect, including all stormwater management practices listed on the survey except road drainage with storm sewer/pipes, and road drainage with culverts and ditches. Stormwater ponds were included in the GSI score since they do have water quality treatment benefits at varying levels, although are primarily used for reducing flow rates (Tharp, 2018). The categories of GSI practice diversity are as follows: Zero GSI practices, 1 practice was considered to have no diversity, 2 to 8 practices were considered low diversity, 9 to 15 practices were considered medium diversity, and 16 to 17 practices were high diversity.

2.2.3 Municipal Maintenance Activities

Survey respondents were asked about various maintenance practices/activities that relate to stormwater management, including landscaping and/or gardening maintenance, stormwater system maintenance, and general maintenance practices (Table 1). Activities included on this list reflect the practical application of maintenance practices and common equipment required to install and maintain most GSI, as well as several road maintenance activities that are common in Vermont and affect drainage and stormwater systems (Hurley & Horner, 2004; Morse, 2017; NYDEC, 2017; Philadelphia Water Department, 2014; US EPA, 2016a; VT Urban & Community Forestry, 2018). Respondents were asked if their municipalities conducted these activities and whether these were done “in-house” (i.e., by municipal crews), contracted out, done by volunteers, not done at all, or not applicable to the town or city.

Table 1. *Maintenance question categories*

Category	Maintenance Practices
Landscaping and/or gardening crews maintenance	Weeding/mulching/planting Irrigation Tree/shrub pruning Mowing Weed whacking/String trimming Hydroseeding with hydraulic sprayer Hauling large machinery with trailers Hauling materials with dump truck
Stormwater system maintenance	Debris collection with large equipment such as bucketloader or backhoe Vacuuming catch basins or underdrains with vactor or combo truck* Flushing subsurface pipes and underdrains with sewer nozzle* Sweet sweeping Leaf collection Debris removal with manual labor (e.g., sediment, leaf litter, trash)
General maintenance practices	Trash removal Snow removal/snow plowing Salting roads Sanding roads Grading roads

Note. *indicates a “below-ground” maintenance activity.

2.2.4 Town Attributes

To better understand town attributes that may serve as limiting or progressing factors for GSI practices in effect, maintenance practices in effect, and perceptions of maintenance capacity, variables were developed both from survey questions and from data obtained from outside resources. Variables obtained from outside sources and used in the analyses presented included population (U.S. Census Bureau, 2010), population density (U.S. Census Bureau, 2010), percent developed imperviousness from the National Land Cover Database (NLCD, 2011) (Xian et al., 2011), MS4 permit designation (VT DEC, 2018b), presence of stormwater bylaws and ordinances (VT League of Cities and

Towns, 2014), existence/status of Stormwater Master Plan (SWMP) (VT DEC, 2018), equalized education property value (EEPV) as an indicator of economic resources (VT Department of Taxes, 2017), and Federal Emergency Management Agency (FEMA) public assistance for Tropical Storm Irene disaster relief as a measure of past exposure to extreme flooding (Vermont Public Radio, 2013). Although the survey instrument asked about presence or status of MS4 designation, Stormwater Master Planning, and stormwater bylaws or ordinances, other publicly available information online and in reports from the Vermont Department of Environmental Conservation and the Vermont League of Cities and Towns was determined to be more reliable than survey responses on these topics (e.g., survey respondents from the same town reported inconsistent master planning status); therefore these other sources were used instead of survey responses.

Population, population density, percent developed imperviousness, and equalized education property values (EEPV) were analyzed to investigate barriers of town size, development patterns, and economic resource indicators. EEPV is an estimate of the taxable appraisal value and used in Vermont's education finance system and to estimate fair market value of each municipality and was used to estimate tax base as an indicator of economic resources in a town (VT Department of Taxes, 2015).

MS4 Permit designation, adoption of stormwater bylaws and ordinances, and status of town Stormwater Master Plans were explored to measure presence of stormwater policies and their effectiveness in relation to GSI practices in place and perceived maintenance capacity. MS4 permits have legal requirements to deal with stormwater with various control measures, whereas stormwater bylaws or ordinances may not be mandated, but suggestions, depending on town. Stormwater master plans are prevention tools that prioritize stormwater retrofit projects, but do not require or enforce them (VT DEC, 2018). FEMA public assistance funding to Vermont towns for Tropical Storm Irene relief provided a quantitative value to the level of destruction a town may have experienced due to a significant past extreme event and was analyzed to explore potential impact on municipal adoption and maintenance capacity of GSI (Vermont Public Radio, 2013). Past experience of stormwater flooding has shown to significantly impact intention to adopt GSI practices among homeowners and residents (Baptiste, 2014; Coleman et al., 2018).

2.2.5 Landscape Visualizations for Maintenance Capacity and Aesthetic Perceptions

Four sets of landscape visualizations were developed for this survey and each set comprised of a pair of images: one photo-simulation perspective view and one conceptual section diagram of each scenario (See Figure 1, A-D). These landscape visualizations depict (A) a conventional inlet and storm sewer design and three bioretention systems with underdrains that each have different vegetative treatments ((B) a grass-vegetated bioretention cell, (C) a grass-and-tree vegetated bioretention cell, and (D) a perennial species-vegetated bioretention cell), placed in the backdrop of a typical downtown Vermont street right-of-way.

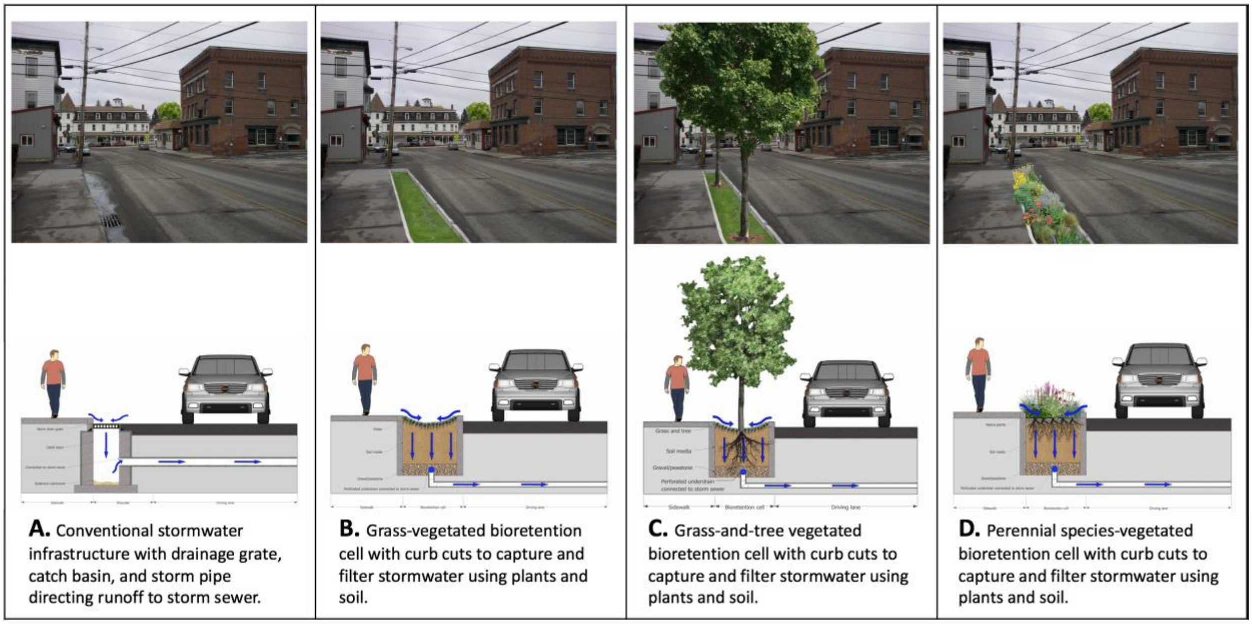

Figure 1, A-D. Landscape visualizations of conventional stormwater infrastructure and three types of curb-cut bioretention planting types, including a photo-simulation perspective and a section diagram.

The background image was chosen to represent a reasonably common downtown street in Vermont. A Vermont town was identified that had a similar population density (77.9 people per square mile) to the average population density in Vermont (67.9 people per square mile) and had a typical medium-sized downtown streetscape (U.S. Census Bureau, 2012). A Vermont town was chosen because place-based images are shown to be more relevant, credible, and easily accessible in a local context and at a scale that matters to people (Shaw et al., 2009; Sheppard et al., 2011; Tress & Tress, 2003). Photo-simulation perspectives were created with Adobe Photoshop (CS6 Version 13.0.5 x 64) to depict a realistic streetview perspective that is detailed, recognizable without needing too much explanation, and in a view that people are used to seeing of streets (Dockerty, Lovett, Sünnenberg, Appleton, & Parry, 2005; Sheppard, 2005; Zube, Simcox, & Law, 1987). Conceptual section diagrams were developed using Google SketchUP (Pro 2017) to depict the underground infrastructure associated with the practice. Variables in the photo-simulations were minimized to isolate responses as best as possible and to elicit initial reactions to specific and obvious changes in pipe infrastructure and vegetation design.

Survey respondents were asked to rank visual appeal associated with each image pair as well as the perceived ability for their town to maintain each practice depicted (Figure 1A-D). The responses were provided on a 7-point Likert scale with labeled points and corresponding positive and negative numbers to clarify the meanings of the scale points and significantly improve reliability and validity (Krosnick, 1999). The survey used “0” to represent neutral and a bipolar rating from “-3” to “3”, where positive numbers are aligned with positive perceptions of visual appeal and ability to maintain, and negative numbers are aligned with negative perceptions; the scale aimed to divide the continuum into approximately equal-sized perceived units (Bettigole, Donovan, Manning, & Austin, 2014; Krosnick, 1999).

Table 2. *Likert scale and text explanations for each landscape visualization ranking*

Visual Appeal	Ability of your town to maintain
3. Very appealing **2.** Appealing **1.** Somewhat appealing **0.** Neutral **-1.** Somewhat unappealing **-2.** Unappealing **-3.** Very Unappealing **x.** I don’t know	**3.** Very able to maintain **2.** Able to maintain **1.** Somewhat able to maintain **0.** Neutral **-1.** Somewhat unable to maintain **-2.** unable to maintain **-3.** Very unable to maintain **x.** I don’t know

2.2.6 Statistical Analysis

All data were analyzed using SPSS Statistics (IBM, Version 24). Descriptive statistics, including frequencies and cross tabulations, were run to analyze demographics, stormwater practices, maintenance activities, and Likert scale ratings of visual appeal and ability to maintain conventional and bioretention stormwater infrastructure systems.

Inferential statistics were run to connect findings back to the population of Vermont. A non-parametric independent samples Kruskal-Wallis test was run to compare differences between the means of independent town attribute variables and dependent perceptions of visual appeal and maintenance capacity variables. For town attributes that had more than two categories, post-hoc pair-wise comparisons were run with the Mann-Whitney independent samples test. Bonferroni adjusted P-value calculations were employed to adjust initial alpha by the number of tests. Spearman's bivariate correlations were also run to test the strength of positive or negative relationships between independent variables with continuous data on perceptions, since the Likert scale was numbered with equal intervals (-3, -2, -1, 0, 1, 2, 3).

Questions about town characteristics, including presence of stormwater practices and maintenance activities, were weighted so that each town equals 1 (e.g., in the case of 3 respondents from one town, each respondent's answer is multiplied by 0.33). Questions about perceptions of visual appeal and town maintenance abilities in response to landscape visualizations were not weighted, and therefore represent municipal officials' individual perspectives, regardless of town.

2.3 Results

2.3.1 Descriptive Statistics

There were 198 valid responses, representing 136 municipalities (55.5% of Vermont's incorporated municipalities), and representing towns from all counties. About two-thirds (66.2%) of towns had one respondent (n=90), 25.7% of towns had two respondents (n=35), 5.2% had three respondents (n=7), three towns had four respondents, and one town had five respondents.

The survey sample closely represented Vermont town population sizes distribution, according the 2010 Census, in which 61.1% of towns were considered rural (<2,500 people) and 38.1% were urban (2,500 people or more). The survey sample was 62.5% rural (<2,500), 23.5% mid-size (2,500-5,000), and 14% urban (>5,000 people) (See Methods for definitions of mid and urban population sizes.) Town Clerks were the primary respondent role in government, accounting for 21.7% of all surveys taken (n=43). Town managers and administrators completed 20.2% of surveys taken (n=40), followed by town zoning administrators (14.6%, n=29), selectboard chairs (10.1%, n=20), town planners (6.1%, n=12), public works directors and selectboard members (each comprising 3.5%, n=7), and road foremen (2.5%, n=5). Table 3 shows survey response rate based on respondent role groupings (see Methods) and town population categories. Manager's and implementers were the primary respondent roles from mid-sized and urban towns (68.6% and 77.1%, respectively), while town clerks, treasurers, and assistants were the primary roles of respondents from rural towns (42%).

Table 3. *Town Population and role in government of survey respondents*

	Rural	Mid	Urban	Total
Town Representation	**62.5%**	23.5%	14.0%	136 towns
Managers & implementers	34.8%	**68.6%**	**77.1%**	**52.1%**
Decision/policy-makers	20.5%	11.8%	8.6%	16.5%
Town clerks, Treasurers, & Assistants	**42.0%**	17.6%	14.3%	31.4%
# of Respondents	**112**	51	35	198

Note. Percentages are shown for the data in columns, e.g., among rural town respondents (n=112), 34.8% were managers or implementers. Town representation row is weighted, e.g., 62.5% of towns represented were rural, but 56.6% of respondents were from rural towns. Role categories and "# of respondents" rows are not weighted. Four respondents were not included in the role groupings because they did not fall under the categories. There were 198 respondents, representing 136 towns. "Rural" towns <2,500 people; "Mid" towns =2,500-5,000 people; "Urban" towns >5,000 people.

2.3.2 Stormwater Management Practices

Figure 2 depicts survey results for stormwater management practices in effect and likely to be implemented in the near future, which included both conventional stormwater management practices and GSI practices. The most present stormwater management practices were primarily designed for conveyance or flow rate reduction, and considered more conventional practices, including road drainage (culverts and ditches, 86.4%; storm sewer and pipes, 43.2%), vegetated or grass swales (50.3%), dry detention pond/basins (20.7%), and wet detention/retention ponds (20.1%).

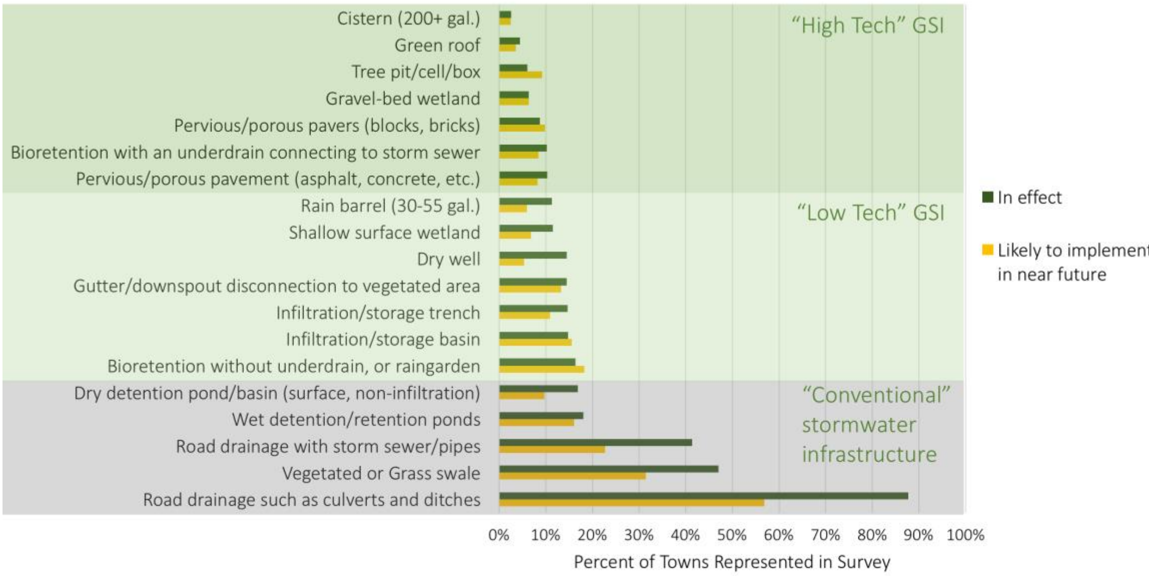

Figure 2. *Present and Planned Practices to Address Stormwater in Vermont Towns*
Includes all responses to the questions, "Which of the following practices are in effect in your town/city to address stormwater" (n=116) and "Which of the following practices is your town/city likely to implement to address stormwater in the near future?" (n= 117). Responses are weighted to represent municipalities equally, e.g. if two respondents from the same town answered the question, each of their answers would be multiplied by .5 or 50% so that each municipality equals a weight of 1.

Compared to these more conventional practices, GSI practices had relatively low rates of presence in Vermont towns surveyed with less than one-fifth of towns having each type of GSI practice present. Among the GSI practice types, "Low tech" GSI were the next most present practices; these include practices like raingardens (bioretention without an underdrain) (16.4%), infiltration/storage basins (14.8%) and trenches (14.7%), gutter/downspout disconnection to vegetated area (14.5%), and rain barrels (11.3%). "High tech" GSI practices were the least present in municipal stormwater management in Vermont; these include bioretention with underdrains (10.2%), pervious or porous pavement (10.3%) and pavers (8.8%), and green roofs (4.5%) (Figure 2).

"Conventional" stormwater infrastructure and a few GSI practices had much lower rates of likeliness of implementation by municipalities in the near future, with reductions typically reported between what is currently in effect to what is planned in the future (Figure 2). Some low-tech and high-tech GSI practices (bioretention without underdrains, gravel bed wetlands, infiltration basins, pervious/porous pavers, and tree pits) had the same or higher rates of likeliness of implementation when compared with practices currently in effect. It was found that the towns reporting that they were likely to implement a GSI practice in the near future, were split fairly evenly between towns that already had implemented the practice and towns that did not currently have that practice in place. However, conflicting answers from multiple responses within the same towns provided too much variability to determine whether a perceived increase from stormwater practices "in effect" to "likely to implement in near future" was valid, and limit deeper statistical analysis.

Table 4. *GSI practice diversity by town size*

	GSI Practice Diversity	Rural	Mid	Urban	Total
0 Practices	0	**63.1%**	27.3%	31.6%	**50.0%**
No diversity	1	14.3%	21.2%	0	14.0%
Low diversity	2-8	21.4%	**45.5%**	**42.1%**	30.2%
Medium diversity	9-15	1.2%	6.1%	26.3%	5.9%
High diversity	16-17	0	0	0	0
	Total (n)	84	33	19	136

Note. Percentages are shown for data in columns. Answers are weighted so that each town = 1. "Rural" towns <2,500 people, "Mid" towns 2,500-5,000 people, "Urban" towns >5,000 people.

The GSI practice diversity measure, shown in Table 4 and 5, was based on the variety of different practices towns had in effect (see Methods). Exactly half of surveyed towns reported zero GSI practices in place and no towns had more than 15 practices in place (Table 4). The majority (63.1%) of rural towns surveyed reported zero GSI practices present, while mid-sized and urban towns fell into the low to medium GSI practice diversity categories (See Table 4).

When stormwater policy and planning presence or status in a town was compared with GSI practice diversity, much higher rates of low and medium GSI practice diversity were reported for towns that had MS4 permits, stormwater bylaws and/or ordinances, and stormwater master plans either completed or in development (See Table 5). Towns that did not have any of these stormwater policies rated much higher in the 0 and 1 GSI practice categories, with over 50% of towns without the stormwater policies reporting zero GSI practices in effect.

Table 5. *GSI practice diversity and Stormwater Policy*

GSI Practice Diversity	# of GSI Practice Types	Towns with MS4[a] permit		Towns with Stormwater Bylaws and/or Ordinances		Towns with Stormwater Master Plan		
		No	Yes	No	Yes	No	Plan in development	Yes
0 Practices	0	**52%**	10%	**57.7%**	30%	**58.9%**	26.7%	31.3%
No diversity	1	**15%**	0	**16.5%**	10%	**17.8%**	0	9.4%
Low diversity	2-8	29.1%	**50%**	24.7%	**42.5%**	20%	46.7%	**53.1%**
Medium diversity	9-15	4%	**40%**	1%	**17.5%**	3.3%	**26.8%**	6.3%
High diversity	16-19	0	0	0	0	0	0	0
	# of Towns	127	10	97	40	90	15	32

Note. Percentages are shown for data in columns. Answers are weighted by town. **Bold** figures represent highest row percentage within stormwater planning/policy category.
a. Municipal Separate Storm Sewer System (MS4) permit.

2.3.3 Municipal Maintenance Activities

Results from the survey's maintenance questions regarding specific maintenance activities of the landscape and stormwater systems (Table 1) that can support GSI, including primary source of labor, are shown in Figure 3.

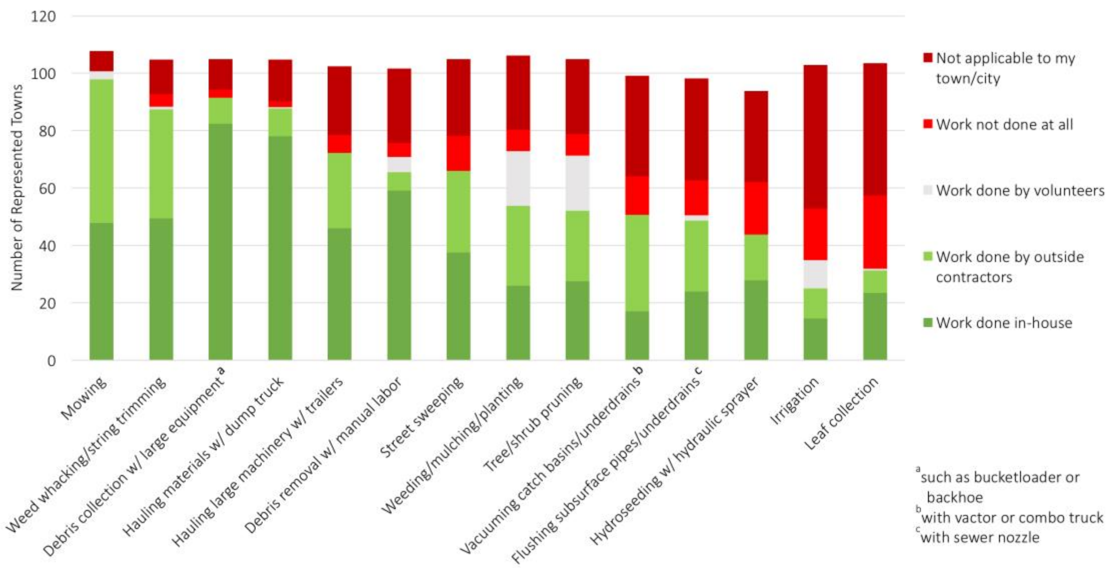

Figure 3. *Maintenance Activities and Source of Labor*
Results reported by municipal officials from Vermont towns responding to survey. Total valid respondents for each category (n) range from 94 to 108. Survey prompted respondents to choose the primary source of *labor (i*.e. "Please choose **only one** of the following"). Answers are weighted so that each town = 1 to represent towns accurately.

About half of surveyed Vermont towns reported to have landscape vegetation maintenance practices done in-house or contracted out, including weeding/mulching/planting (50.7%) and tree/shrub pruning (49.6%), with urban towns having much higher rates of primarily in-house labor for these practices. About one-sixth of towns rely on volunteer labor for weeding/mulching/planting (17.9%) and tree/shrub pruning (18.3%); two-thirds of the towns that rely on volunteer labor for landscape vegetation maintenance were rural (65.5% and 65.4%, respectively). Over 80% of towns have lawn care practices done in-house or contracted out, including mowing (90.9%) and weed whacking/string trimming (83.4%), with urban towns having higher rates of in-house capacity and mid-sized and rural towns more likely to have contractors do the work. All towns had fairly high rates of hauling large machinery with trailers (70.5%) and materials with a dump truck (83.8%), with most hauling primarily done in-house.

Practices most cited as “not done at all” or considered “not applicable” were irrigation (66.1%) and hydroseeding with a hydraulic sprayer (53.3%), primarily by rural towns, but also by over a third of mid-sized towns.

Overall, towns reported relatively high rates of debris collection with large equipment (78.5%) and debris removal with manual labor (58.2%) done in-house, except rural towns had much lower rates of manual labor in-house (41.9%) than mid-sized (76.9%) and urban towns (92.9%). Few towns contracted out debris collection and removal (8.6% and 6.2% respectively). All urban towns conduct street sweeping either in-house or contracted out, while 81.4% of mid-sized towns do, and almost half of rural towns do (46.9%). Vermont towns have very high capacities for “general” maintenance practices with most road maintenance done in-house: snow removal or snow plowing (91.9%), sanding roads (91.6%), salting roads (88.7%), and grading roads (86.9%). Trash removal is mostly contracted out (52.7%), with some towns removing trash in-house (22.2%).

Over 80% of mid-sized and urban towns already conduct maintenance activities in-house, contracted out, or done by volunteers to maintain most GSI practices, including weeding/mulching/planting (mid 85.1%; urban 92.8%), tree or shrub pruning (88%: 93.4%), vacuuming catch basins or underdrains (84.6%; 93.8%), flushing subsurface pipes and underdrains (80.8%; 92.8%), mowing (92.6%; 100%), weed whacking or string trimming (88.8%; 100%), hauling large machinery with trailers (80.8%; 85.7%) and materials with dump truck (85.2%; 100%), debris collection with large equipment (96.3%; 93.3%), and debris removal with manual labor (84.6%; 92.9%).

Over half of rural towns have the current maintenance activities in-house, contracted out, or done by volunteers to conduct most of the *above-ground* maintenance of GSI, including weeding/mulching/planting (56%), tree or shrub pruning (53.9%), mowing (92.5%), weed whacking or string trimming (78.1%), hauling large machinery with trailers (64%) and materials with dump truck (79.7%), debris collection with large equipment (80.9%), and debris removal with manual labor (58.1%). About a quarter of rural towns have the more specialized stormwater maintenance activities to conduct *below-ground* maintenance, including vacuuming catch basins or underdrains (25.4%), flushing subsurface pipes and underdrains (30.6%). Urban towns have much higher rates of in-house sewer nozzles (71.4%) and vactor or combo trucks (68.8%) compared to less than a quarter of mid-sized towns (in-house: sewer nozzle, 23.1%; vactor/combo truck, 11.5%) and less than one-sixth of rural towns (in-house: sewer nozzle, 15.3%; vactor/combo truck, 6.8%). Urban towns are also more likely to have street sweepers (80%) and trailers for large machinery (64.3%) in-house, compared to around half of mid-sized towns (in-house: street sweepers, 48.1%; trailers, 46.2%) and one to two-fifths of rural towns (in-house: street sweepers, 20.3%; trailers, 41%). Over two-thirds of all towns reported in-house use of bucket loaders or backhoes and dump trucks for stormwater practice-related maintenance activities.

2.3.4 Landscape Visualization Perceptions

Figure 4 and 5 show results from the survey's landscape visualization questions, which asked about visual appeal and perceived ability for respondent's town to maintain a conventional storm sewer system and three vegetated roadside bioretention cells, shown in image pairs (refer to Figure 1, A-D).

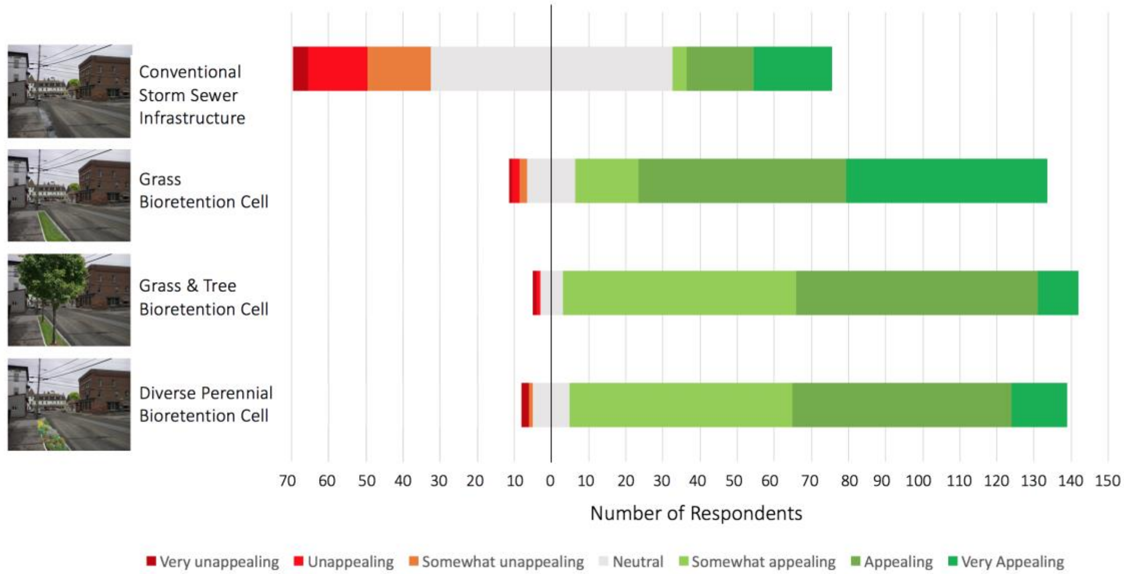

Figure 4. *Visual Appeal Rankings of Stormwater Infrastructure Visualizations*
Municipal officials' visual appeal of simulated conventional storm sewer system and three vegetated roadside bioretention cells. Frequency of responses shown for scale of visual appeal, from "-3. very unappealing" to "3. very appealing", with "0. Neutral" in the middle.

Grass-vegetated, grass-and-tree vegetated, and perennial species-vegetated bioretention cells had a median score of "appealing" (Figure 4). Conventional stormwater infrastructure had a neutral visual appeal rating with a median of 0. The grass-vegetated bioretention cell had the highest visual appeal ratings, with 75.9% of respondents thinking it was appealing or very appealing, while about half of respondents thought the grass-and-tree vegetated and the perennial species-vegetated bioretention cells were appealing or very appealing (51.7% and 50.3%, respectively). The grass-and-tree and perennial species-vegetated treatments had much higher rates of respondents thinking they were "somewhat appealing" than the grass-vegetated treatment (42.9% and 40.8%, respectively). A much higher percentage of respondents thought that the grass-vegetated bioretention cell was “very appealing” (37.2%) compared to grass-and-tree vegetated bioretention (7.5%) and perennial species-vegetated bioretention cell (10.2%). Among the categories of roles in government surveyed (Table 3), “decision and policy-makers” had slightly higher ranked visual appeal ratings (very appealing, appealing) for all the bioretention vegetation treatments, (86.4% grass; 68.1% grass and tree; 58.2% perennial) compared to “managers and implementers” (76.2% grass; 51.1% grass and tree; 50.6% perennial) and “town clerks, treasurers, and assistants” (71% grass; 42.5% grass and tree; 41.4% perennial). Decision and policy makers ranked the perennial species vegetated bioretention with almost double the rate of “very appealing” (grass-and-tree, 13.6%; perennial species, 18.2%) compared to the managers and implementers (grass-and-tree, 7.1%; perennial species, 12%) and over five times the rate compared to town clerks, treasurers, and assistants (grass-and-tree, 2.5%; perennial species, 2.4%).

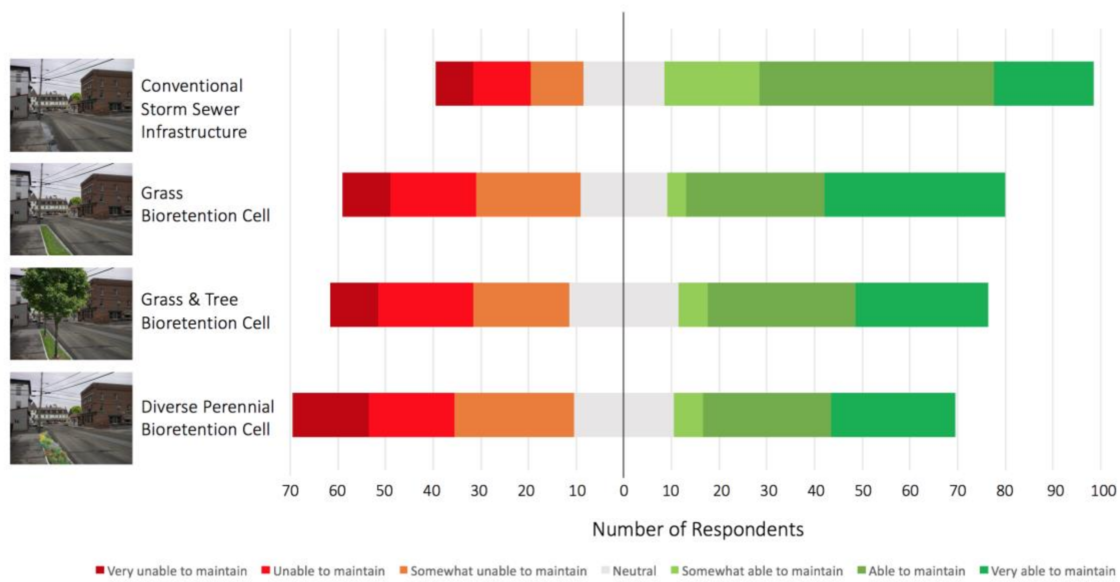

Figure 5. *Municipal Ability to Maintain Rankings of Landscape Visualizations*
Municipal officials’ perceived ability for town to maintain simulated conventional storm sewer system and three vegetated roadside bioretention cells. Frequency of responses shown for scale of maintenance ability, from “-3. Very unable to maintain” to “3. Very able to maintain”, with “0. Neutral” in the middle.

The median perceived maintenance capacity was “able to maintain” for the conventional storm sewer system, “somewhat able to maintain” for grass-vegetated bioretention, and “neutral” for grass-and-tree and perennial species-vegetated bioretention (Figure 5). The perceived capacity to maintain all three bioretention treatments was split fairly evenly between positive and negative perceptions of maintainability, with about half of municipal officials’ indicating positive perceptions of maintainability (51.1% grass-vegetated, 47.1% grass-and-tree vegetated, and 42.5% perennial species-vegetated bioretention cells), and about half indicating neutral or negative perceptions of maintainability.

If these data are analyzed by town population size categories (See Appendix B), perceived capacity goes down for each group (rural, mid, urban) with each subsequent treatment (conventional, grass-vegetated bioretention, grass-and-tree vegetated bioretention, and perennial species-vegetated bioretention, Figure 1A-D respectively), except urban towns’ perceived capacity to maintain street trees is equal to grass systems, and rural towns perceived capacity to maintain diverse perennial systems is equal to grass-and-tree systems (within one percentage point). There were higher rates in confidence for maintaining conventional infrastructure among urban and mid-sized towns (53.8% of respondents from urban towns reported being “able” or “very able to maintain”; 57.9% of mid-sized town respondents reported being able or very able to maintain; 45.9% of rural respondents reported being able or very able to maintain).

Overall, over a third of rural municipal officials think their town has some capacity (very able, able, or somewhat able) to maintain the bioretention systems (42.7% grass; 37.9% grass-and-tree; 37.3% perennial). Between forty and fifty percent or less of mid-sized towns' municipal officials think their town has some ability to maintain the bioretention systems (50%; 46.1%; 39.6%); and about three-quarters or less of urban officials think their town has some capacity to maintain the bioretention systems (76.9%; 76%; 61.5%).

Figure 6A-H show boxplots of mean ranked responses of perceived ability for respondent's town to maintain the infrastructure in each image pair according to town attribute categories (e.g. urban, mid, rural). Kruskal-Wallis independent samples and Mann-Whitney pair-wise comparisons compare differences of means and rate significance of town attributes' influence on maintainability perceptions.

Greater perceived capacity to maintain conventional storm sewer infrastructure shown in the landscape visualizations was significantly correlated with higher population size, population density, percent developed imperviousness, EEPV, and GSI practice variety score (all at significance level of p value <0.001).

Survey respondents' perceived capacity for their town to maintain the grass-vegetated and grass-and-tree vegetated bioretention cells were significantly (p-value <0.05) positively influenced by the following attributes (See Figure 6A-H): urban towns ranked significantly higher than rural towns, greater than $500 million worth of EEPV ranked significantly higher than less than $500 million EEPV, having stormwater policies in place or in development (MS4, stormwater master plan, stormwater bylaws/ordinances) ranked significantly higher than not having policies in place, population densities of more than 100 people per square mile ranked significantly higher than towns with less than 40 people per square mile, and higher diversity of GSI practices in place rated significantly higher in perceptions of maintainability.

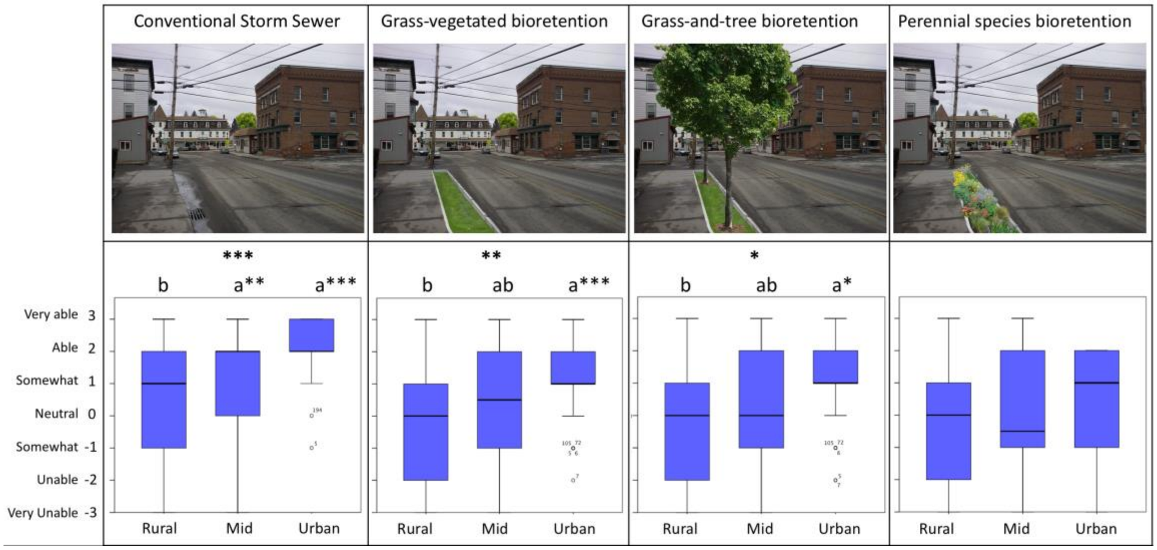

Figure 6A. Town Population Size.

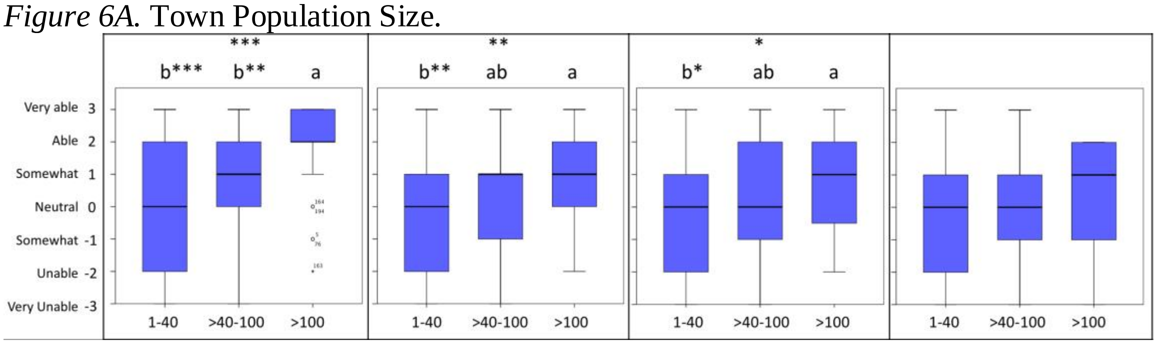

Figure 6B. Population Density.

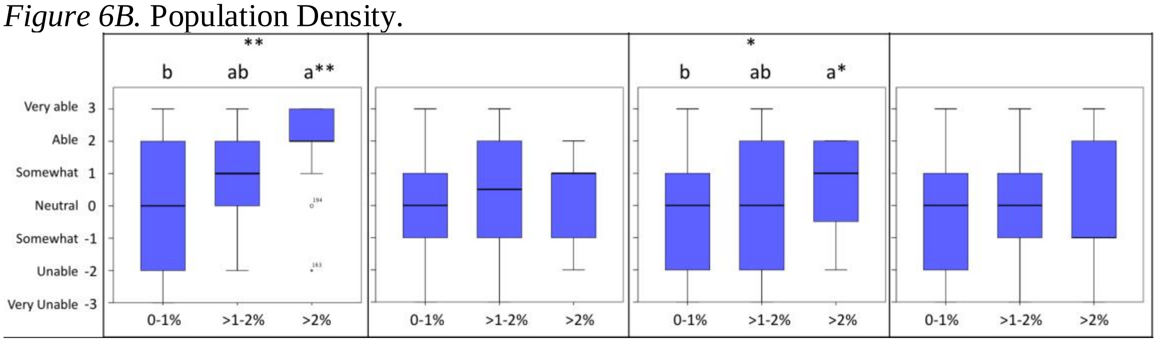

Figure 6C. Percent Development Imperviousness.

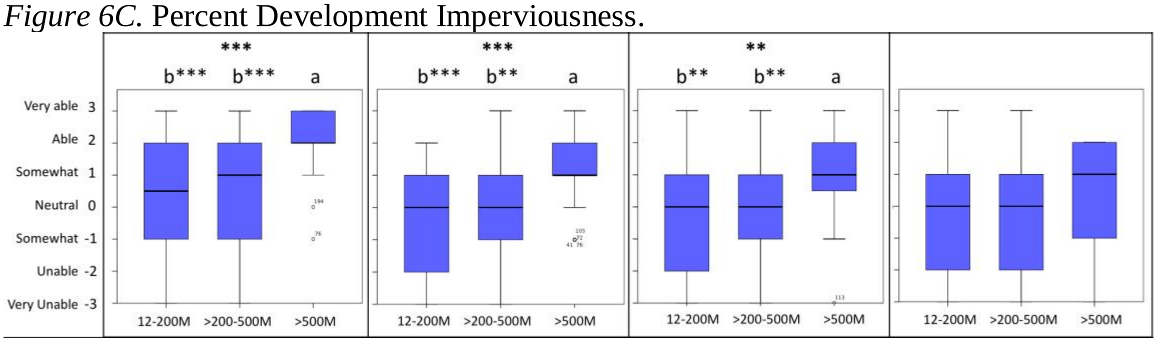

Figure 6D. Equalized Education Property Value.

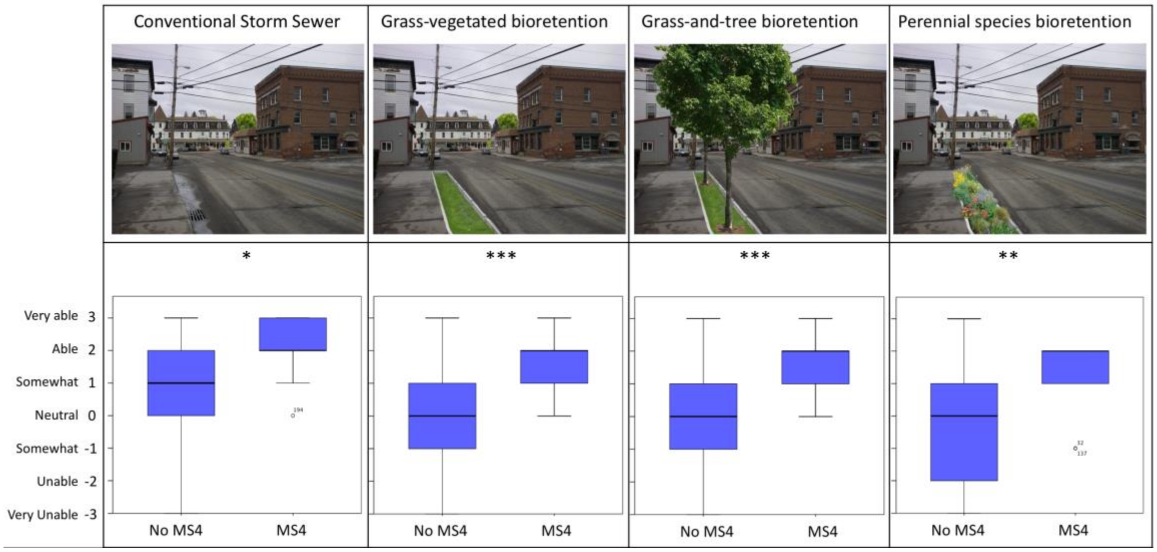

Figure 6E. MS4 Permit.

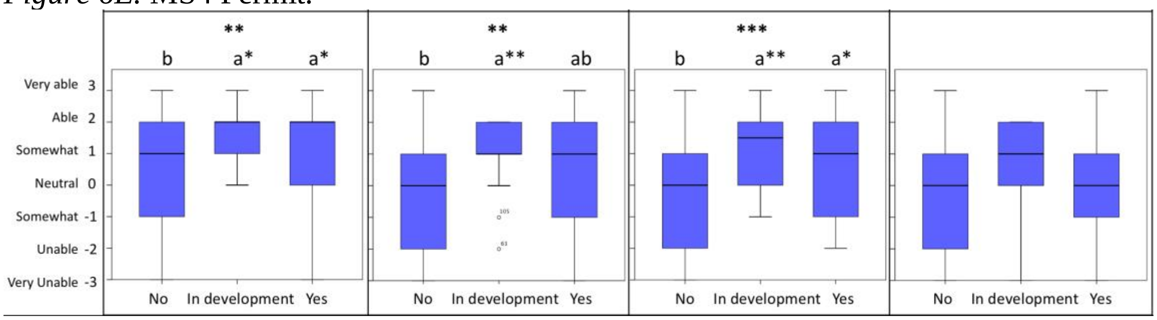

Figure 6F. Stormwater Master Plan.

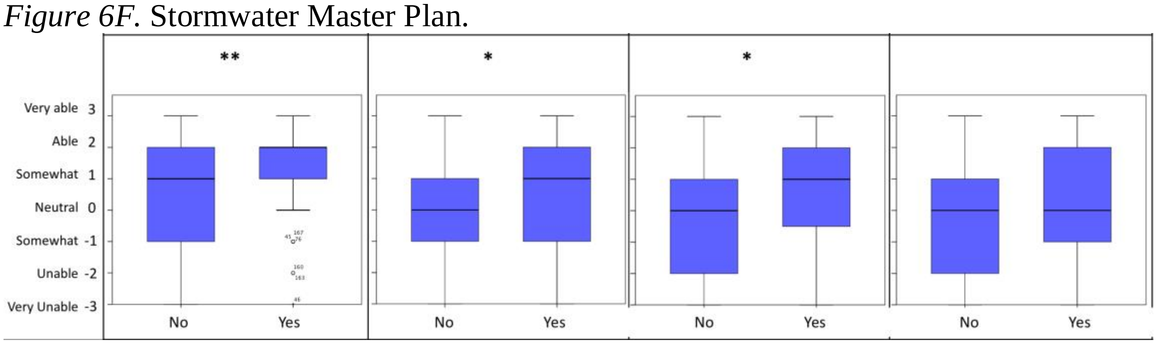

Figure 6G. Stormwater Bylaws and/or Ordinances.

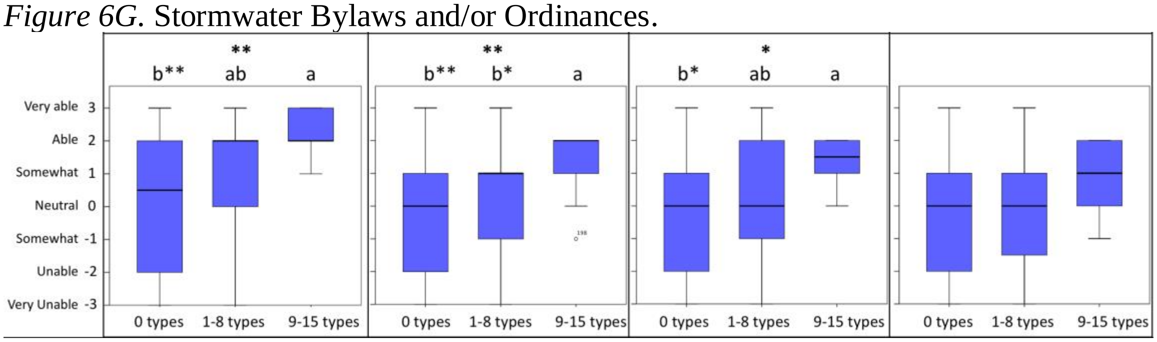

Figure 6H. GSI Diversity Score.

Figure 6A-H. Significance of town attributes influencing perceived maintenance capacity ratings. Kruskal-Wallis non-parametric tests show significance across independent ‘town attribute’ variable categories on dependent ‘perceived maintainability’ variable. Mann-Whitney pair-wise comparisons with Bonferroni adjusted p-values show significance between independent ‘town attribute’ variable categories (letter system, e.g., a, b) on dependent ‘perceived maintainability’ variable. Asterisks mark significance levels as follows: *** = p-value <0.001, ** = p-value <0.01, * = p=value <0.05.

Spearman correlations of continuous independent variable datasets show that higher population (p value <0.01), population density (p value <0.05), EEPV (p value <0.001), and GSI practice diversity (p value < 0.001) positively correlate with higher perceptions of maintainability.

Percent of land area that was impervious significantly influenced grass-and-tree vegetated bioretention maintenance perceptions, but not the grass-vegetated bioretention maintenance perceptions, where more than 2% developed imperviousness was significantly ranked higher than less than 1% developed imperviousness. Similarly, Spearman correlations found the higher the percent of developed imperviousness, the higher perceived capacity for maintaining grass-and-tree vegetated bioretention (p value <0.01). The town attributes analyzed did not significantly influence the perceived capacity to maintain the perennial species-vegetated bioretention cell, except for towns/cities with MS4 designation, which positively influenced higher perceived maintenance capacity (p-value <0.01). All respondents had similarly low perceptions of their towns’ capacities to maintain the perennial-vegetated system, regardless of most town characteristics. Experience of extreme flooding from Hurricane Irene in 2011 as measured by FEMA public assistance funding to towns had no significant impact on perceptions of maintenance capacity for any of the landscape visualizations.

2.4 Discussion

2.4.1 Stormwater Management Practices

Vegetated or grass swales were the most commonly present GSI practice in Vermont towns, with 50.3% of towns having at least one in effect (See Figure 2). The most present GSI practices were "low tech" and require less technical expertise (See Figure 2). The more "high tech" GSI practices, requiring greater technical and engineering expertise, were the least present (See Figure 2). These findings are similar to Coleman et al.'s (2018) study of residential intention to adopt GSI practices in Vermont, which found lower tech practices like "diversion of roof runoff" and "infiltration trench" as the most common currently adopted practice by households, and the higher tech "green roof" and "tree box filter" the least adopted.

Outreach, education, and demonstration projects in the public realm to encourage private implementation could all help in the future as a way to increase presence of "low tech" GSI practices, due to the relatively low costs and minimal technical expertise required to implement them (CCRPC, 2018; VT DEC, 2016). Rural towns that may not have storm sewers or drains or areas of high impervious surface are more suited to "low tech" GSI practices that do not have underground pipes and drains, such as raingardens and infiltration trenches and basins, or vegetative green infrastructure solutions such as riparian buffers and forest and wetland restoration (Coleman et al., 2018). The "high tech" GSI practices are excellent candidates for greater municipal implementation, especially in urban areas, to address stormwater in highly impervious areas and serve as educational and aesthetically pleasing demonstration projects (VT UCF, 2018). In the future, implementation of the high-tech practices is likely to be dependent on opportunities for skilled professionals (engineers, designers, contractors) to receive training opportunities and gain direct hands-on experience with such systems.

Overall, most GSI practices were more likely to be implemented in the near future than conventional stormwater infrastructure in comparison to current rates of those same practices in effect (See Figure 2). This shows a promising outlook for the implementation of GSI practices in Vermont towns and cities in the near future, especially for bioretention without underdrains, infiltration/storage basins, pervious/porous pavers, tree pit/cell/boxes, gravel-bed wetlands, gutter/downspout disconnection to vegetated areas, and cisterns, which had higher rates or almost equal rates (within 10%) of likeliness to implement compared to current rates of presence (Figure 2).

Mid-sized and urban towns had a higher diversity of GSI practices in effect than rural towns (Table 4), most likely because they have been the focus of stormwater policies and runoff reduction efforts due to higher concentrations of impervious area. However, rural towns also contribute significant amounts of stormwater runoff and pollution to waterways, especially from extensive dirt road networks (Buchanan et al., 2013; Wemple et al., 2013). The term stormwater may be associated more with urban areas and rural areas could benefit from place-based education and outreach on stormwater runoff issues unique to rural areas to support and complement recent policy changes for municipal roads in Vermont, requiring adherence to TMDLs or other water quality restoration requirements (Coleman et al., 2018; VPDES, 2018).

The fairly low diversity of types of GSI practices currently in effect in Vermont towns are most likely due to the relatively recent shift in water quality policy to address stormwater runoff and permit MS4s and TMDLs for impaired water bodies, which began in the early 2000s (VT DEC, 2018a, 2018c, 2018b). The reissuance of the 2012 Vermont MS4 General Permit requires municipalities with MS4s to develop Flow Restoration Plans, which require BMPs (including GSI) to be installed as soon as possible, but mandated within 20 years of permit issuance, which could be more than a decade before BMPs are implemented (Osherenko, 2013; US EPA, 2016b; VT DEC, 2018b). As indicated by Table 5, having more diverse GSI types in place is more likely in those municipalities that are required to have MS4 permits or some type of stormwater ordinance, bylaw, or master plan, indicating the successful impact of stormwater policy on GSI adoption and capacity to consider and implement a wider diversity of GSI practices. This may be a result of the BMP requirements as "control measures" in MS4 communities (VT DEC, 2018b). Whether their stormwater permits, plans, and policies were federally or state mandated, or done voluntarily, these cities and towns are more likely to have experimented with various GSI types than towns that have had less time or incentive to implement GSI. It is evident that rural and urban towns are very different contexts when it comes to GSI practices in place and planned for the future; therefore, both outreach and education about GSI practices and methods to encourage and mandate GSI will need to be tailored to meet existing knowledge, landscape characteristics, and municipal capacity.

Further analysis of the survey question regarding GSI practices was not explored in greater depth due to the limitation of the questions only asking *the presence* of stormwater practices and not *the quantity of practices* in effect or intended for the future (e.g., a respondent would have answered the survey the same way if her town had installed one or twenty raingardens). Another limitation is the high rate of conflicting responses from respondents from the same town, which indicates either misinterpretation of the question or a lack of knowledge of practices in place. Definitions of stormwater management practices were not included in the survey due to space limitations and the expectation that municipal officials would likely have some familiarity with these practices given that the Vermont Stormwater Management Manual Rule had just come out (effective July 1st, 2017) and that if the municipality had implemented any of these practices or intended to in the near future, they would be familiar; given the wide variety of respondents' roles in government, that assumption should be questioned for future research.

2.4.2 Municipal Maintenance Activities

Maintenance activities in place show Vermont towns are well poised to take on operation and maintenance of GSI with over 80% of mid-sized and urban towns having the current maintenance activities (in-house, contracted out, or done by volunteers) to maintain most GSI practices (above- and belowground) and over half of rural towns having the current maintenance activities to maintain the above-ground components of most GSI practices (Figure 3). More information is needed on municipal maintenance budgets and hours dedicated to these practices, data which were not collected for this study, but it is likely more funding and trained personnel are needed for towns to effectively manage new GSI projects (NY DEC, 2017; Roy et al., 2008; US EPA, 2016a; Vail & Meyer, 2012).

Landscaping and stormwater system maintenance activities that seem well established (done in house or contracted out by at least two-thirds of towns) are mowing, weed whacking and string trimming, hauling large machinery with trailers, debris collection with large equipment (e.g. bucketloader or backhoe), debris removal with manual labor, and hauling materials with a dump truck (See Figure 3). Landscaping practices that could be invested in more (either not done in-house or contracted out by half of towns) are weeding/mulching/planting, irrigation, and tree or shrub pruning.

In-house labor was much more prevalent in urban towns while mid-sized and rural towns contracted out more maintenance activities, including weeding/mulching/planting, tree/shrub pruning, lawn care practices, and vacuuming and flushing out underground pipes and drains. Urban towns likely have the infrastructure and funding capacity to support more full-time year-round employees while some mid-sized and most rural towns do not. Equipment that could be invested in and shared by small towns are hydraulic sprayers for hydroseeding, vactor or combo trucks for vacuuming catch basins or underdrains, sewer nozzles and truck to flush subsurface pipes, and street sweepers. Vermont towns have relatively low street sweeping rates (63% in-house or contracted out) when you consider this practice to have basic stormwater benefit (Sutherland & Jelen, 1996) and provides important preventative measures to remove sediment, organic matter, and trash from roadways before it ever enters GSI inlets, cells, and basins (Selbig & Bannerman, 2007).

Across all town population sizes, dependence on volunteer labor was the highest for landscape vegetation maintenance practices including weeding/mulching/planting and tree or shrub pruning. This may indicate a lack of capacity for municipalities to hire horticulture or arboriculture professionals or a lack of public spaces that require this expertise. The high rates (19 towns) of volunteer labor for weeding, mulching, planting, and pruning may reflect organizations like garden clubs that could play an important maintenance role in smaller towns with less tax base and little existing stormwater infrastructure of any kind. The key role that volunteers could play in GSI maintenance is supported by the following respondent comments: “The town's ability to maintain such aesthetically pleasing stormwater infrastructure may well depend on how engaged community volunteers/volunteer groups are, rather than town employees alone” and “I might think the models that use vegetation will require an amount of community time to maintain with care, watering, replacement on failure etc.” Outreach and education about garden-related maintenance specific to GSI to volunteer garden organizations could have an important impact in small towns with limited municipal maintenance capacities. GSI design recommendations and plans can be tailored to municipal maintenance capacity and capacity of committed volunteer organizations for gardening practices. However, some level of municipal maintenance oversight and organization is required for success of project, i.e., towns cannot depend on volunteer labor solely (Nassauer, 2018). ‘Adopt a BMP’ programs, such as the ‘Adopt-a-Rain Garden’ program in Vermont, provide a good example of municipal oversight with committed volunteers, because both are held accountable with contracts (American Rivers, 2016; CCRPC, 2018).

When horticultural or arboricultural knowledge is lacking, GSI vegetation designs can include simple planting palettes consisting of a couple herbaceous species, each species in large groupings, that can be easily identified, weeded around, and cut back once a year in the fall. It has been shown that limiting a plant palette to massing’s of 4 to

6 species aids with plant identification, ease of weeding, visual appeal, and overall success of project (Upchurch et al., 2018). Another key design solution for ease of maintenance is to make sediment/debris removal as simple as possible with pre-treatment forebays and “internal forebays” for sediment capture and easy removal, and increasing ponding depths by 50% to account for common installation problems and sediment build up (Hurley, 2013; Upchurch et al., 2018).

The findings on existing capacity to conduct maintenance activities are promising for Vermont towns’ potential capacity to adapt to GSI maintenance protocols, given more funding and policies to support GSI, and more targeted education and outreach to maintenance professionals on GSI operation and maintenance, including hands-on trainings on the proper procedures and schedule for completing them. Furthermore, having implemented more diverse types of GSI was significantly correlated with perceptions about GSI maintainability (Figure 6H), which could indicate that maintenance capacity allowed for the adoption of a greater variety of GSI practices, but it could also indicate Vermont towns’ ability to adapt maintenance capacity to take on new GSI by expanding existing programs (NY DEC, 2017).

Targeted outreach and education to engineers, landscape architects, designers, planners, managers, and contractors on GSI operation and maintenance and design solutions for ease of maintenance is also crucial. Consulting maintenance departments in planning and design phases is key for ease of maintenance, reducing costs, and project acceptance and success (US EPA, 2013). Tailoring GSI design plans for the capacity of the town is key with consideration for maintenance capacity, willingness of maintenance workers of volunteers to manage different vegetation designs, and level of knowledge and expertise present to maintain practices effectively.

2.4.3 Landscape Visualization Perceptions: Visual Appeal

The aesthetic appeal of the three different vegetation types of bioretention cells shown in the pairs of images (Figure 1B,C,D) appears to not be a major barrier to practice acceptance. There does however seem to be less consistent positive visual appeal of diverse perennial species-vegetated bioretention, which may stem from other factors, such as respondents' consideration of likely maintenance involved skewing answers about visual appeal. This is evidenced by decision and policy makers ranking the more diversely vegetated bioretention with almost double the rate of "very appealing" compared to the managers and implementers and town clerks, treasurers, and assistants. Managers and implementers may be letting their knowledge of management aspects of the diversely vegetated bioretention cells skew their true levels of visual appeal, though that would not explain the low "very visually appealing" scores that town clerks, treasurers, and assistants rated for grass-and-tree and diverse perennial vegetation. It is unknown whether it was the perennials altogether that were perceived as less visually appealing or the particular number of species and arrangement of plants that were shown in the Figure 1D that caused lower perceived visual appeal. It has been found that species evenness (i.e., similar numbers of each species present) in addition to species diversity is found to be aesthetically pleasing (Graves, Pearson, & Turner, 2017). Nassauer (1995) has found that clean edges and borders, designed to contain 'messier' naturalistic plantings, are more visually pleasing. The perennial species-vegetated bioretention landscape visualization (Figure 1D) has relatively high species evenness, but the edges are not very clean with plants spilling over the side of the curbs. It is unknown whether it was the perennials altogether that were not considered “very appealing”, or the particular number of species and arrangement of plants that were shown in Figure 1D. In future research, a simpler perennial plant palette (e.g., larger groupings of native grasses or herbaceous perennials) with lower diversity of plants would be worth testing with municipal stormwater audiences.

The grass-vegetated bioretention cell (Figure 1B) with mown turf rated the highest for “very appealing” (37.2%) among all respondents and all roles in government, which may be reflecting the deeply ingrained value of and aesthetic appeal for lawns in American culture (Bormann, Balmori, & Geballe, 2001; Nassauer, 1995a). The favorable visual appeal responses to the grass-vegetated bioretention cell could have also been an effect of respondents’ having just seen the conventional storm sewer infrastructure and rating the grass vegetation in comparison to the paved surfaces, leading to a slight over-exaggeration of the visual appeal of turf. Respondents were not asked to compare the four landscape visualizations to each other (e.g., a respondent could rate all the landscape visualizations the same way), but they could have done this unintentionally by comparing each image pair with the last (however, respondents were able to go back in the survey and change their answers).

2.4.4 Landscape Visualization Perceptions: Ability to Maintain

Urban and mid-sized towns had significantly higher perceived capacity to maintain conventional storm sewer infrastructure depicted in the image pair (Figure 1A) than rural towns (Figure 6A); importantly, given Vermont's generally rural setting, many rural Vermont towns do not have any existing stormwater pipe systems, so this image pair depicting a conventional stormwater pipe system would not be typical for those towns. A question about types of stormwater systems present in at least part of a city or town, in a different section of the survey, helped to confirm this, finding that of rural towns represented in the survey, only 31.8% had a system for stormwater runoff only and 3.5% had a combined sewer system, compared to mid-sized towns, where 62.5% had a separate stormwater system and 18.8% had a combined sewer system, and urban towns, where 73.7% had a separate stormwater system and 36.8% had a combined sewer system for at least part of the drainage (respondents could check both if they had both types of stormwater systems in their town).

Less than half of respondents reported that their town has the ability ("able to maintain" or "very able to maintain") to maintain the three different vegetated bioretention cells shown in the landscape visualization pairs (See Figure 1A-D and Figure 5). There were also variations of perceived capacity to maintain the different vegetated bioretention treatments, indicating that the responses were driven primarily by above-ground vegetated aspects of bioretention design (Figure 5).

Urban municipalities had significantly higher perceptions of maintainability for both the grass-vegetated and grass-and-tree vegetated bioretention cells than rural, and higher (but not significant) perceptions of ability to maintain perennial species-vegetated bioretention than rural towns. It is evident that urban municipalities have a higher capacity to maintain street trees, backed by 73.4% of urban towns that report conducting tree or shrub pruning (in-house or contracted out) and 61.6% report irrigation activities (in-house or contracted out). Mid-sized towns do not significantly perceive maintenance capacity differently from urban or rural towns for the bioretention scenarios, but descend incrementally in perceived capacity from grass-vegetated bioretention to grass-and-tree vegetated bioretention to perennial species-vegetated bioretention (Figure 6A). Rural towns have significantly lower perceived capacity than urban towns for the grass-vegetated bioretention and grass-and-tree vegetated, but comparatively higher perceptions of capacity to maintain the perennial species-vegetated bioretention relative to other town sizes (Figure 6A). About one-third (34.8%) of rural towns conduct weeding/mulching/planting in-house or contracted out, while another 21.2% depend on volunteer labor for these specialized gardening practices.

Overall, there were relatively neutral maintainability perceptions for perennial species-vegetated bioretention (Figure 1D), most likely due to the more specialized knowledge and skills required to maintain biodiverse gardens (Sandström, Angelstam, & Khakee, 2006). As with understanding aesthetic preferences associated with perennial species bioretention plantings, future research on maintenance perceptions could also explore using simpler perennial species mixes.

There also seems to be a cultural barrier among maintenance crews, illustrated by this respondent's comments to the landscape visualization questions, "grounds staff like power equipment to maintain vegetation, and hand-pulling of weeds doesn't appeal to them and they won't do it." The need for horticultural and arboricultural knowledge and expertise was illustrated by the following respondents' comments, "our road crew might need help from a horticulturist or plant expert to maintain trees and flowers," and "there is little to no ability to maintain high needs infrastructure -- we'd likely kill it all within a couple of years." Leveraging existing municipal resources, such as Master Gardener programs, to provide expertise and support could help overcome knowledge barriers of plant identification and care (American Rivers, 2016).

Other prominent maintenance concerns were winter maintenance issues and the need for additional funding and personnel to expand on what is currently conducted. A variety of maintenance concerns were expressed in the following comments. "Northern Vermont: ice, salt, silty sand causes major issues with roadside infiltration;" "Our snowplows would hit the trees and dig up the flowers/damage the beds;" "winter maintenance is a "nightmare";" and "while all these projects seem lovely, the reality of the Vermont winters, and the difficult snow management issues, make them very impractical." These comments illustrate concerns that could be stemming from limited or inaccurate understanding of GSI maintenance requirements, particularly in the street right-of-way depicted in the landscape visualizations, given the demonstrated success of curbed bioretention cells as a best practice for accommodating snow plowing (Roy et al., 2008). The lower perceptions of municipal maintenance ability could be from negative perceptions of GSI, resistance to change or to take on more maintenance work on the municipal level, or lack of knowledge for what is involved in maintaining each of the systems (Roy et. al., 2008; Rowe et. al., 2016; Vail & Meyer, 2012; Uittenbroek, 2013).

Specific maintenance activities involved with each landscape visualization were not listed due to limited space and potential for survey-taker fatigue since these questions were at the end of the survey. Notably, in the survey, the landscape visualization questions were asked before the questions on maintenance activities done by one's town (See Appendix A and survey questions 38-45); this was to get a "gut reaction" to the images (Figure 1A-D) regarding visual appeal and maintenance capacity based on prior knowledge, without having yet thought about the detailed list of possible GSI maintenance activities. A limitation to this approach is that the survey taker, or municipal official responding may not necessarily know what is involved for maintenance of each practice. This notion is expressed by these respondents' comments, "not really sure what would be best or how to answer this section or what would be management/ maintenance problems with each system" and "ability to maintain is difficult to determine as we don't need to do it currently," in response to landscape visualization questions.

2.4.5 Landscape Visualization Perceptions: Town Attributes

Factors of town size, wealth, and stormwater policy all significantly impact perceived ability for a town to maintain conventional storm sewer infrastructure and vegetated bioretention cell infrastructure in the landscape visualizations. Greater town population size and population density correlated positively with perceived ability to maintain grass bioretention and grass-and-tree bioretention cells and higher percent developed imperviousness correlated with higher perceptions of grass-and-tree bioretention maintainability (See Figure 6A,B). Small (typically rural) towns do not have the resources for additional maintenance, illustrated by these respondent's comments about the landscape visualization questions: "small towns can't afford added personnel to maintain new infrastructure easily," "we have just enough staff and equipment to maintain standard roads…we have no capacity to maintain enhancements at all," "small road crew only; once a year mowing is a stretch, and we've got quite a ways to go on better ditching," "we can barely maintain what we have," "towns have limited staff to perform regular maintenance on living systems." These factors of town size are significant for maintenance capacity and barriers to maintain bioretention and other GSI practices since they influence the size and capacity of a municipal government. These factors cannot be altered, but maintenance protocols and policy can account for town size and municipal capacity and be tailored to town size.

EEPV as a measure of town tax base was significantly correlated with perceived capacity of all bioretention treatments except the perennial species-vegetated bioretention cell (See Figure 6D). Tax base and funding are significant barriers to GSI maintenance, illustrated by the following respondents' comments: "great ideas but requires more staff for the extra maintenance and would increase costs to taxpayers," "most of the proposed methods would require a lot of hand maintenance or weedwhacking. This takes a lot of time which would make the ongoing costs high." Identifying funding mechanisms for ongoing operation and maintenance are a primary challenge (American Rivers, 2016). For towns with lower tax base, but higher percentages of impervious surfaces, grants or policies may help increase capacity for GSI. Stormwater utilities or an impervious tax can help to more equitably link the harm of impervious surface area to the costs of offsetting the stormwater runoff with GSI so that people responsible for the buildings, parking lots, and driveways pay for the impact of increased stormwater runoff (American Rivers, 2016). For larger towns (mostly urban), a dedicated stormwater program will play a key role in GSI maintenance, pointed out by a respondent, "we hope to be better able to maintain once we have a stormwater program with dedicated funding."

It is known that the visibility of water issues, such as extreme flooding or algal blooms, promote stronger action and policy than invisible issues (e.g., warmer water temperatures) (Brown, 2017). This was seen in Vermont with extreme flooding in Spring 2011 from Tropical Storm Irene and torrential spring rains, which raised awareness of increasing heavy precipitation events and their impact on inadequate infrastructure. However, in our analysis municipalities that had received FEMA funding to rebuild post-Irene did not appear to have statistically different perceptions of GSI. The public assistance data may not have been a sufficient measure of exposure to extreme flooding or it could have been too long ago to impact current perceptions of municipal capacity. Future research could examine impacts of extreme flooding on municipal adoption and maintenance more in-depth.

Stormwater policy significantly influenced perceived capacity to maintain all three bioretention designs (Figure 6E-G). Figure 6E,F,G indicate that municipal officials in towns with existing stormwater permits, plans, and policies are more confident in the towns' ability to maintain GSI systems. Towns with stormwater bylaws, ordinances, or master plans under development (i.e. actively working on their plans) had significantly higher perceptions of maintainability for grass-vegetated bioretention and grass-and-tree vegetated bioretention cells than towns without stormwwater bylaws, ordinances, or master plans. Towns with stormwater master plans already completed had significantly higher perceptions of maintainability for the grass-and-tree bioretention cell than towns without master plans. This suggests that not only towns with stormwater master plans, but towns currently developing them, may be more enthusiastic about GSI maintainability, potentially because of increased familiarity with stormwater management concepts. A cited outcome of developing and implementing stormwater master plans is "greater awareness and ownership by the public in finding and implementing stormwater solutions" (VT DEC, 2018, p. 5), which may be magnified during the development process.

MS4 permit status was the only town attribute to significantly influence maintenance perceptions of the perennial species-vegetated bioretention cell (and all the bioretention cell vegetation treatments), indicating that stormwater policy that involves enforcement of GSI may be the most effective type of policy for increasing capacity (See Figure 6E). GSI maintenance manuals recommend that towns and cities establish a stormwater ordinance requiring a municipal maintenance protocol that includes routine procedures, and establishes responsibility, inspection, and enforcement (American Rivers, 2016; NY DEC, 2017). It is evident that requiring adherence to stormwater runoff goals and enforcing it may be the most effective way to build municipal capacity. A survey respondent summed up this finding nicely in the comments section of the survey:

> "Municipalities will implement green infrastructure when they are either A) mandated to do so through permit requirements or B) provided sufficient funding to do so. Alternatively, if the proper regulations/bylaws were in place to make development and redevelopment upgrade municipal infrastructure as a condition of approval then we would also be willing and ready to maintain such systems. It all comes down to what we are told to do and how we can fund it."

Although visual appeal and maintainability of GSI systems were key questions for this research, the findings of this study show that policy and funding seem to be the most significant barriers to adopting and maintaining GSI other than inherent and relatively unchangeable factors of town population and size.

2.4.6 Limitations & Future Research

Limitations of this study stem from efforts to minimize survey length to encourage participation and prevent survey taker fatigue. Previously mentioned limitations in survey questions include not providing definitions of the stormwater practices presented, not asking for the number of stormwater practices in effect or planned, not requesting maintenance budgets or hours dedicated to maintenance activities, and not including the information on the required maintenance procedures for each stormwater infrastructure practice shown in the landscape visualizations (See Full Survey in Appendix A). Additionally, co-benefits of each stormwater infrastructure practice could be included (i.e., deeply rooted perennials provide more water infiltration, uptake, and evapotranspiration than mown turf or that street trees provide shading and urban climate cooling); however, including these may have influenced respondent perceptions.

Future research in Vermont and other rural areas should consider the character of rural towns more in-depth and tailor the background image for landscape visualizations to better reflect the rural character. If researching vegetation options for bioretention or other GSI practices, a simplified perennial planting plan (e.g., massings of a couple species of native grasses) would be helpful to understand what respondents are reacting to when it comes to more complicated planting plans. Furthermore, visual appeal as a barrier is largely a public issue and residents of a town or city should be surveyed on aesthetic preferences for various GSI practices and vegetation plans. Finally, to understand nuances of municipal maintenance capacity and to hear concerns of maintenance departments surrounding the operation and maintenance of GSI, focus groups or interviews with municipal officials on challenges and barriers to implement and maintain GSI should be conducted.

2.5 Conclusion

Findings of this study show a promising landscape for the advancement of implementation and maintenance of GSI in Vermont with presence of GSI practices seeming to grow, maintenance activities required for more GSI system already being conducted by most urban towns and many mid-sized and rural towns, and visual appeal of vegetated bioretention designs based on landscape visualizations not appearing to be a major barrier. Perceived maintenance capacity of municipal officials seems to reflect maintenance activities currently conducted, i.e. perceptions of capacity don't seem to be a major barrier as opposed to actual maintenance capacity, but more information on budgets and time dedicated to the practices is needed to know actual municipal maintenance capacity. Urban (>5,000 people), mid-sized (2,500-5,00 people), and rural (<2,500) municipalities provide very distinct contexts for the implementation and maintenance of GSI; therefore, outreach, education (e.g., professional trainings), policy, regulations, GSI design recommendations, and maintenance procedures must be tailored to town/city characteristics. Stormwater policy and planning, and especially policy that requires or enforces adherence to water quantity and quality goals, appears to be very effective at advancing GSI adoption and improving perceived maintenance capacity for stormwater systems. The results of this study point to the following solutions to advance GSI implementation and project success in Vermont and elsewhere: (1) more outreach, education, and targeted hands-on trainings for professionals, (2) more policies, plans, and regulations that encourage, require and enforce GSI (American Rivers, 2016; NY DEC, 2017), (3) more funding, and (4) maintenance-friendly designs.

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2.7 Appendices

APPENDIX A. Survey Instrument (See end of thesis).

APPENDIX B.

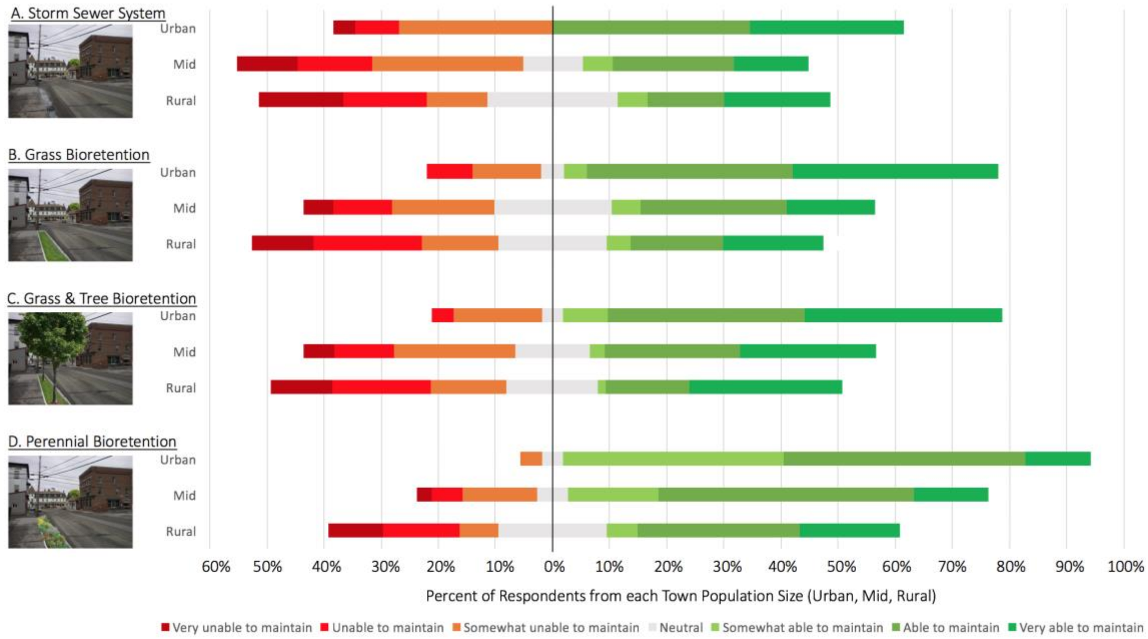

Figure 7. *Perceived 'Ability to Maintain' Rankings of Landscape Visualizations by Town Population Size*

Municipal officials' perceived ability for their town to maintain simulated (A) conventional storm sewer system, (B) grass-vegetated bioretention cell, (C) grass-and-tree vegetated bioretention cell, and (D) perennial species-vegetated bioretention cell. Percent of responses from town population size categories (Urban, Mid, Rural) are shown for rankings of maintenance ability, from "-3. Very unable to maintain" to "3. Very able to maintain", with "0. Neutral" in the middle.

CHAPTER 3: HEALING WATER & PEOPLE:

CULTURAL ECOSYSTEM SERVICES AS A FRAMEWORK FOR DESIGNING MULTIFUNCTIONAL GREEN STORMWATER INFRASTRUCTURE

Abstract

In retrofitting stormwater management practices in urban areas, there is ripe opportunity to include multifunctional green stormwater infrastructure (GSI) design to make the nonmaterial and intangible benefits of green spaces, or cultural ecosystem services (CES), more evident to people. CES are often the most valued ecosystem services in urban areas due to the lack of visibility of biophysical services and can often provide the most compelling reasons to protect or create healthy ecosystems.

Study methods include an in-depth literature review, guided by a CES framework, of design elements that can be included in GSI to create multifunctional urban green spaces. CES categories of aesthetic, recreation, education, sense of place, social capital, and stewardship benefits frame a set of design elements, principles, practices, and documented benefits to guide multifunctional design of GSI. Findings include the importance of participatory processes to elicit diverse landscape values, visible water pathways, biodiversity, prospect and refuge, mystery and complexity, spaces for creative use, accessibility, interaction with water, species diversity and evenness, abundant blooms, interpretive signage, and other artful and biophilic design features to enhance feelings of preference, pleasure, relaxation, stress reduction, mental health, physical health, learning, connection, and inclusion.

Landscape designs that support ecological functions can often be overlooked or misunderstood; incorporating multifunctional and aesthetically pleasing design can help communicate ecological processes and functions while also creating unique places that people will value. We can build ecological and cultural value by simultaneously treating the water and telling its story aesthetically in a landscape language that creates meaning and instills a sense of place. The health and wellbeing of water and people must be integrated into the design of GSI for cities to be ecologically functional and culturally meaningful to their populations.

3.1 Introduction

3.1.1 Urbanization & Cultural Ecosystem Services

Urbanization limits experiences in nature and skews perceptions of the relationships between people and nature, essentially blindfolding people to their direct dependence on ecosystems because ecosystem processes are not as visible (Bendt, Barthel, & Colding, 2013). This lack of contact with nature is evident in issues such as 'nature deficit disorder', which has negative developmental impacts, including emotional, cognitive, and physical difficulties in children (Aerts, Honnay, & Van Nieuwenhuyse, 2018; Louv, 2008). A result of limited time spent in nature results in what Pyle (1978) calls 'extinction-of-experience', or the amnesia about relationships and dependence on diverse ecosystems. Dennis and James (2017, p. 17) state, "it is recognized that urban areas, now home to the majority of the global population, are the nexus of understanding how ecosystem services contribute to human well-being and the challenges present in enhancing and safeguarding those services." Over 80% of U.S. citizens live in urban areas and rising, heightening the need to address the issue of cities becoming sinks of ecological services and move them in the direction of becoming sources of ecosystem services (Krasny, Lundholm, Shava, Lee, & Kobori, 2013).

Cultural Ecosystem Services are the "nonmaterial benefits (e.g., capabilities and experiences) that arise from human-ecosystem relationships" (Chan, Satterfield, & Goldstein, 2012, p. 9) and are mediated through personal, cultural, political, and economic processes. There are four categories of CES that are widely agreed upon and provide a core of benefits, including recreation, spirituality, aesthetic, and artistic (Gould

& Lincoln, 2017). Other CES categories identified by researchers include cultural heritage, education, social capital/relations, sense of place, existence, knowledge systems, cultural diversity, identity, bequest, ingenuity, perspective, and life teaching (Gould & Lincoln, 2017; Milcu, Hanspach, Abson, & Fischer, 2013; Groot, van de Berg, & Amelung, 2005). Cultural Ecosystem Services are often the most highly valued ES by inhabitants of a place and may be connected to environmental behavior (Comberti, Thornton, Wyllie de Echeverria, & Patterson, 2015; Gobster, Nassauer, Daniel, & Fry, 2007; Martín-López et al., 2012; Orenstein, 2013). Chan et al. (2012) emphasize that CES present some of the most compelling reasons to conserve ecosystems, since they are inherently personal, emotional, and vital to quality of life. Studies have found that CES are often seen as the most valuable ES to people in urban areas because they are directly perceived and experienced through engagement with urban ecosystems on a regular basis, such as recreational or social connectivity opportunities of parks (Andersson, Tengö, McPhearson, & Kremer, 2015; Bolund & Hunhammar, 1999; Larson et al., 2016), whereas many biophysical ES are often invisible, hidden under streets or beyond city limits, and require in-depth understanding of ecological processes and how they impact human health and wellbeing (Kumar & Kumar, 2008).

CES provided by urban green spaces are important contributors to quality of life, where "recreational aspects of all urban ecosystems, with possibilities to play and rest, are perhaps the highest valued ecosystem service in cities" (Bolund & Hunhammar, 1999). Urban green spaces provide the "vegetation [that] is essential to achieving the quality of life that creates a great city and that makes it possible for people to live a reasonable life within an urban environment" (Botkin and Beveridge, 1997, p. 18). Urban green spaces enhance the livability of cities by providing biophysical and cultural ecosystem services that benefit "physical health, psychological wellbeing, and social cohesion" (Botzat, Fischer, & Kowarik, 2016, p. 220), through exposure to pleasant environments and encouraging health-promoting activities (Henderson, Greenway, & Phillips, 2007; Jorgensen & Gobster, 2010; Lovell, Wheeler, Higgins, Irvine, & Depledge, 2014).

It has been demonstrated that humans are unconsciously influenced by their environment (Kaplan & Kaplan, 1989), and receive benefits of physical and mental health and emotional and social well-being from natural elements, or detriments to health and wellbeing from a lack thereof (Bolund & Hunhammar, 1999; J. H. Heerwagen, 2009; J. Heerwagen & Hase, 2001; S. Kellert, Heerwagen, & Martin L. Mador, 2008; Roger S Ulrich, 1983; Wilson, 1984). Many studies have shown benefits of interacting with natural spaces and 'greenness' to hundreds of attributes and phenomena (Botzat et al., 2016; Hartig et al., 2011; James, Banay, Hart, & Laden, 2015; Jorgensen & Gobster, 2010; Lovell et al., 2014; van den Berg et al., 2015). Empirically documented effects of urban green spaces (including greenways, greenness, and all forms of nature in built environments) include reducing stress and anxiety (Berto, 2014; Huang, Ritschard, Sampson, & Taha, 1992; Mennis, Mason, & Ambrus, 2018); improving cognitive function (Bratman, Daily, Levy, & Gross, 2015; Dadvand et al., 2015); reducing risk of depressive symptoms (Bezold et al., 2018); increasing productivity in workplaces (Hartig et al., 2011; Kaplan & Kaplan, 1989); vegetation and views of vegetation improving performance and attention in classrooms (Li & Sullivan, 2016; Wu et al., 2014); improving social interactions and sense of community (Collado & Staats, 2016; James, Hart, Banay, & Laden, 2016); enhancing relaxation and moods (Park, Song, Choi, Son, & Miyazaki, 2016; Roger S Ulrich, 1979). Views of nature speeding up recovery in hospitals (Dilani, 2001; R S Ulrich, 1984); parks and greenspaces motivate and improve benefits of physical activity (Cohen et al., 2015; Mytton, Townsend, Rutter, & Foster, 2012; Sharma-Brymer, Brymer, & Davids, 2015); and tree canopies reduce crime rates (Kondo, Han, Donovan, & MacDonald, 2017; Troy, Morgan Grove, & O'Neil-Dunne, 2012).

Bendt, Barthel, and Colding (2013) call for an incorporation of living ecosystems into multiple facets of urban life, as well as integration of rich cultural diversity in those green spaces to combat 'extinction-of-experience' for all people in dense areas. Notably, green spaces and the benefits they provide are not equitably distributed across urban populations, based on socioeconomic determinants (V. Jennings, Larson, & Yun, 2016), which needs to be corrected by implementing quality green spaces in dense and poor urban areas (Dunn, 2010). Interaction with nature is essential to motivate action to protect, enhance, and provide ES; "we need to feel nature to love it" (Bendt, Barthel, and Colding, 2013, p. 19), and finding more creative and diverse ways to articulate the value of ecosystems will help to achieve this goal. Andersson et al. (2015, p. 165) argue that CES…

> "…may serve as a more useful entry point [than biophysical ES] for managing nature in cities for multifunctionality. A focus on CES could potentially draw on already existing appreciation of nature to build awareness of the broader suite of ES, and therefore help to embed multifunctional ecosystems, and the services they generate, in urban landscapes and the minds of urbanites, planners, managers, and educators."

This view of tapping into the experiences and emotions relating to our innate need for interaction with natural spaces as a gateway for urban ES stewardship is central to this paper; urban areas must be designed for multifunctionality to provide ES and CES in addition to highly competitive economic and infrastructural needs, therefore, we need to elicit our most salient reason for creating natural spaces, our personal connection to nature.

3.1.2 Cultural Ecosystem Services as a Framework for Design

The flow of services from ecosystems to humans is largely covered in the ES literature (Chan et al., 2011; Costanza et al., 1997; de Groot et al., 2013; MEA, 2005; Milcu et al., 2013), but the reciprocal flow from humans to ecosystems is not as well-documented. What Comberti et al. (2015) describe as ‘services to ecosystems’ (S2E) are the “actions humans have taken in the past and currently that modify ecosystems to enhance the quality or quantity of the services they provide, whilst maintaining the general health of the cognized ecosystem over time” (p. 247). This alternative framework, which builds upon the ES framework and conceptualizes the relationship as a reciprocal loop, emphasizes the inclusion of maintenance and enhancement of ecosystems in management strategies based on ES, and the importance of ethnographic research in ES-based interventions (Comberti et al., 2015).

Design processes and the visual renderings, maps, drawings, models, simulations, and stories they produce offer a well-established method to more fully value CES and provide S2E. Landscape architecture and ecological design manifest S2E when design practices are (1) backed by ecological and social science, (2) effective at providing ES and supporting surrounding ecosystems in ES-based interventions, and (3) are well-received and maintained by a community.

3.1.3 Green Stormwater Infrastructure

Green stormwater infrastructure (GSI) is a suite of ecological design practices that provide many ES, or S2E, by emulating the functions of natural landscapes to provide hydrological processes of capture, storage, water infiltration, groundwater recharge, evapotranspiration, and water filtration and treatment of runoff before it enters waterways (Ahiablame, Engel, & Chaubey, 2012; Dietz, 2007; Hunt et al., 2010).

Stormwater runoff is the rainwater and snowmelt that washes off of impervious or partially impervious surfaces created by roofs, parking lots, roads, driveways, lawns, and other compacted soils or areas with a lack of vegetation (Booth, Hartley, & Jackson, 2002; Dietz & Clausen, 2008). Whereas a natural landscape would have the topography and vegetative cover to capture and more gradually convey stormwater, aiding processes of infiltration and evapotranspiration, impervious surfaces cause deluges of stormwater runoff that increase peak hydrologic flows in streams and cause erosion and flooding (Carle, Halpin, & Stow, 2005; D. B. Jennings & Jarnagin, 2002). Stormwater runoff also carries pollutants found on the landscape with it (e.g., nutrients and bacteria from organic matter and fertilizers, oil and grease from vehicles, heavy metals from infrastructure, deicing salt from roads, and chemicals from pesticides and herbicides); these pollutants flow directly into nearby waterways or are piped through storm sewer systems into nearby waterways, typically without treatment (Farrelly & Brown, 2011; Line & White, 2007; Steinman, Isely, & Thompson, 2015; US EPA, 2013).

It has become evident that conventional “grey” stormwater infrastructure, characterized by pipes, sewers, drains, culverts, and ditches that capture and convey stormwater runoff quickly to nearby waterways, cause significant harm to water quality, aquatic ecosystem, and water resources vital to ecosystem and human health (Carpenter et al., 1998; Correll, 1998; Roy et al., 2008; Steinman et al., 2015). GSI offers a solution to stormwater runoff that mimics hydrologic flows of a pre-development landscape to reduce runoff volumes and transport of pollutants downstream, offsetting the harmful impacts of impervious cover (Roy et. al, 2008).

GSI utilizes plants, soils, rocks, structural features, and other materials to provide regulating ES of flood control and water purification (Ahiablame et al., 2012; Davis, Hunt, Traver, & Clar, 2009; Hunt et al., 2010; Kratky et al., 2017; Roy-Poirier, Champagne, & Filion, 2010). Implementing GSI to manage stormwater runoff can transform buildings and streets from being detrimental to beneficial, providing ES (or S2E) by recharging groundwater, irrigating native vegetation, reusing rainwater, reducing urban heat island effects, improving air quality, sequestering carbon, increasing biodiversity, and providing wildlife habitat islands and corridors (Ando & Netusil, 2018; Dunn, 2010; Foster, Lowe, & Winkelman, 2011; Moore & Hunt, 2012; Pataki et al., 2011). Examples of GSI treatments include bioretention cells and raingardens, rain barrels, vegetated swales, street trees and tree cells, infiltration trenches and basins, constructed wetlands, green roofs, and pervious pavers and pavements.

Many GSI practices emulate some functions of wetlands, and wetlands have been cited as the most valuable urban ecosystem for the area they occupy because they provide the most ES, including air filtering and carbon sequestration, microclimate regulation, noise reduction, rainwater drainage, sewage treatment, biodiversity, and cultural services of recreation and education (Bolund & Hunhammar, 1999; Moore & Hunt, 2012). GSI is a perfect example of eco-revelatory design, revealing vital ecosystem processes in streetscapes and other public areas, which can help to strengthen people's connection to water storage and filtration processes and the ES they provide. Design goals for multifunctional GSI are to make complex natural processes visible and comprehensible and to emphasize our connection to them (Robert L Thayer, 1998; van Bohemen, 2002).

GSI provides important ecological services that are often lacking in urban areas, and CES provide a "conceptual bridging element between various social and ecological constructs" (Milcu et al., 2013, p. 9) that can more effectively nest biophysical processes in the built environment of a town or city. The well-documented need in towns and cities to adopt more effective methods to manage stormwater (Barbosa, Fernandes, & David, 2012; Farrelly & Brown, 2011; Roy et al., 2008; US EPA, 2007, 2002) offers an opportunity to transform urban public spaces into functional stormwater treatment areas that also provide a multitude of benefits to people and ecosystems, including human health and wellbeing, economic benefits, and healthy downstream ecosystems. GSI can potentially provide greater aesthetic, recreation, education, sense of place, social capital, and stewardship benefits in dense areas by providing natural elements in previously "grey" impervious areas (Andersson et al., 2014, 2015; Botzat et al., 2016; T Elmqvist et al., 2015; Kati & Jari, 2016; La Rosa, Spyra, & Inostroza, 2016). For example, New Yorkers varying in experience with GSI from practitioners to random online survey-takers, cited CES as the most valued aspect of green infrastructure in New York City, such as recreation and aesthetic value (Miller & Montalto, 2018). Furthermore, the co-beneficial CES provided by multifunctional GSI may be essential catalysts for garnering the public support needed to implement stormwater treatment measures in urban settings with competing interests. GSI and the design processes it entails may help to characterize some of our intangible connections to nature to benefit people and the ecosystems on which we depend.

3.1.4 Objectives & Research Questions

The objectives of this literature review are to identify CES derived from certain types of landscapes and landscape elements that can potentially be replicated in GSI design. I draw on design theories, principles, and practices with the potential to enhance CES and provide examples on how they can be applied in GSI design. As a result, the set of multifunctional GSI design guidelines provided will help to describe, visualize, and characterize CES with design examples to better articulate value in the planning processes in a form that is context-specific and applicable.

Research Questions:

1. What cultural ecosystem services (benefits, values, or constituents of wellbeing) can be enhanced through documented landscape patterns, designs, and processes?
2. What design theories, principles, and practices can be applied to green stormwater infrastructure to provide CES?

3.2 Methods

A review of literature explores documented benefits that arise from design practices and principles, knowledge interventions, and participatory processes that can enhance CES experienced by participants. This research draws from numerous fields including ecology, culture and place studies, ecological economics, psychology, biological conservation, biodiversity, health and medicine, landscape ecology, environmental and ecological design, and many others. Findings draw from many theories pertaining to human-nature relations, including the biophilia hypothesis (S. R. Kellert & Wilson, 1993; Wilson, 1984), prospect refuge theory (Appleton, 1975), information processing theory (Kaplan & Kaplan, 1989), ecological aesthetics (Nassauer, 1992), aesthetics of care (Nassauer, 1995), landscape preferences (Zube, Sell, & Taylor, 1982), affective theory (Roger S Ulrich, 1983), and psychological restoration theory (Hartig et al., 2011). These theories elucidate environmental preferences as an indication of beneficial conditions to health and wellbeing from an evolutionary perspective as well as environmental experiences and documented benefits on health and wellbeing (Hartig et al., 2011). In addition, design fields of ecological design (Hurley & Stromberg, 2008), biophilic design (J. Heerwagen & Hase, 2001; S. Kellert et al., 2008; S. R. Kellert & Calabrese, 2015), environmental and regenerative design, artful rainwater design (Echols & Pennypacker, 2008a), healing gardens (Marcus & Sachs, 2014; Stigsdotter & Grahn, 2002), natural playgrounds (Laaksoharju, Rappe, & Kaivola, 2012), and others bring theories to life, providing design principles, practices, examples, and visual resources that bring clarity and characterization to elements that enhance CES.

By making effective stormwater management beautiful, GSI can be celebrated as ecological and cultural amenity, providing spaces that serve the full range of ecosystem services, from clean water provision to sense of place. The following sections will outline six CES categories (aesthetic, education, recreation, sense of place, social capital, and stewardship) and how design elements that may enhance these functions and the benefits humans receive. These six CES categories were chosen due to their relative prevalence in CES literature and their application to GSI (Gould & Lincoln, 2017; MEA, 2005; Milcu et al., 2013; Rudolf de Groot et al., 2005). Aesthetic and recreation CES goals align with changing landscape patterns to be more aesthetically pleasing and inviting; social capital and stewardship goals arise out of community involvement and participatory processes; education and sense of place goals involve opportunities to learn about ecology and water processes and viewers' roles within those spatial and temporal processes. All CES require design interventions, knowledge interventions, and participatory processes to be most fruitful.

3.3 Results & Discussion: Multifunctional GSI Design for CES

3.3.1 Aesthetic

Aesthetic benefits of urban green spaces are critical for enhancing overall CES provided because they are often the first CES that visitors encounter: the sense of beauty experienced. Aesthetic value is found to be indispensable in the eyes of the broader public and land uses that have high aesthetic value appear to be the most resistant to change (Milcu et al., 2013; Rudolf de Groot et al., 2005; Tielbörger, Fleischer, Menzel, Metz, & Sternberg, 2010). For example, the pastoral agrarian landscape of Vermont is no longer dependent on the extensive farming required for the primarily productivist society of the past, but is maintained for viewsheds and attachment to place; "the visual aesthetic is particularly powerful for its value to landowners and in the way that visual perception of landscape is one means to sense the other cultural attributes landscape offers" (Morse et al., 2014, p. 235). It seems that aesthetic value can be a gateway for other cultural benefits of identity, sense of place, and spirituality. Gobster and Nassauer (2007, p. 964) define the landscape aesthetic experience as, "a feeling of pleasure attributable to directly perceivable characteristics of spatially and/or temporally arrayed landscape patterns." In addition, it is evident that there is overwhelming similarity in aesthetic preferences between people from different groups and from different backgrounds (Kaplan & Kaplan, 1989; Rudolf de Groot et al., 2005). This section aims to define a few of the patterns that are key for enhancing aesthetic benefits of GSI. It is important that outside views and views from within are aesthetically pleasing to promote the entry, interaction and engagement required for other CES, such as education, recreation, social capital, and stewardship. Aesthetic benefits shown in Table 6 are organized by element, including water, vegetation, and rocks and other structural materials.

Water provides a rich aesthetic experience with reflections and movement, complex texture and color, malleable to the touch, and auditory sounds of a soothing trickle or crashing of falling water, and has been shown to be restorative by reducing stress and enhancing feelings of relaxation and calm through views (Kaplan & Kaplan, 1989; Roger S Ulrich, 1983; M. White et al., 2010) and sound (Alvarsson, Wiens, & Nilsson, 2010). Water can be emphasized in GSI design by creatively adapting ecologically functional features of conveyance, capture, and retention to provide beautiful, interactive, and dynamic water features. It is important to enhance the visual experience of water by drawing attention to the line of water flow, creating a clear path that viewers can follow, and designing multiple levels to capture and convey water by harnessing gravity (Echols & Pennypacker, 2008a). The "Line of beauty" is a theory for the universal aesthetic beauty of an S-shaped or serpentine curved line that signifies liveliness, activity, and excitement to the viewer in contrast with straight lines (Biederman & Vessel, 2016). Focal points, hidden and revealed water flows, variety, rhythm, repetition, and contrast provide design principles to guide design of GSI to enhance aesthetic benefits through the medium of water (Boults & Sullivan, 2010). Themes and cohesive patterns, such as representing a local river gorge with locally-sourced boulders, can create harmony and achieve balance in GSI design, inviting the viewer to use their imagination.

Contrasting water with other elements can create visual interest and communicate human intention and care (Echols & Pennypacker, 2008b; Nassauer, 1995). For example, water is captured from nearby gutters and conveyed by a series of cascading copper flumes and scuppers, providing a focal point, contrasting metal and water, and creating rhythm and repetition of falling water, creating a rich multisensory experience. Enhancing the intrigue and complexity with a variety of volumes of water, surfaces it flows over, and varying amounts and rates of water falling, can enhance aesthetic appeal (Echols & Pennypacker, 2008).

Table 6. *Aesthetic Benefits: GSI Design Elements, Principles, and Practices*

Design Element **Design principles**	**Design Practices**	**Potential benefits to wellbeing**	**Studies**
Water Focal points Variety Rhythm Repetition Hide & Reveal	Visible conveyance of water path - Use of gravity - Multiple levels of water - "Line of Beauty", S-shaped curved line - hide & reveal water - variety of structures & materials that carry water	Excite attention Inspire liveliness Pleasurable Calming Relaxation Preference Positive emotional response	Theory/Design: (Echols & Pennypacker, 2008a; Hogarth, 2001) Empirical: (Biederman & Vessel, 2016; Heerwagen & Orians, 1993; Ulrich, 1983; White et al., 2010)
	Rhythm and texture of moving water - 'Heraclitean' movement, e.g., soft movement of water over pebbles - Reflect light off water & surrounding surfaces, e.g., glass, ceramic, shiny metal	Pleasurable Calming Relaxation Preference Positive emotional response Tranquility, peace	Theory/Design: (Kellert & Calabrese, 2015) Empirical: (Alvarsson et al., 2010; Biederman & Vessel, 2016)
	Sound & Tactile - Variety of volumes flow rates of falling water - Variety of pool sizes	Improved concentration Memory restoration Reduce stress Tranquility Lower heart rate/blood pressure	Theory/Design: (Echols & Pennypacker, 2008a) Empirical: (Alvarsson et al., 2010)
Vegetation Variety Balance Repetition Contrast Boundary Organized complexity	Species richness (diversity) - biodiversity - natives - many textures, colors, foliage types, blooms, sizes, growth forms	Preference Pleasurable Signify care/intention	Empirical: (Dennis & James, 2017; Graves, Pearson, & Turner, 2017; Lindemann-Matthies, Junge, & Matthies, 2010)
	Species evenness (even numbers) - massing plants - repetitive grouping patterns	Preference Pleasurable Signify care/intention	Empirical: (Graves et al., 2017; Lindemann-Matthies et al., 2010)
	Colorful and abundant blooms - contrasting or analogous color schemes - season-long blooms	Preference Pleasurable Signify care/intention	Empirical: (Graves et al., 2017; Nassauer, 1993, 1995)
	Edges/frames: - Mown edges and grass strips - Distinct changes in plant composition	Preference Pleasurable Signify care/intention	Empirical: (Gobster et al., 2007; Nassauer, 1993, 1995, 2011)

Design Element **Design principles**	**Design Practices**	**Potential benefits to wellbeing**	**Studies**
Rocks (& other structural surfaces) Boundary Abstraction Contrast Balance	Natural materials - Wood - Local stone - Brick - Mosaic (clay, glass)	Calming	Theory/Design: (Kellert & Calabrese, 2015) Empirical: (Ikei, Song, & Miyazaki, 2017)
	Borders/Frames: - Stone walls, weirs - Granite/concrete curbing - Fences - Terraces	Signify care/intention Orderliness	Empirical: (Gobster et al., 2007; Nassauer, 1995)

Vegetation puts the “greenness” in urban green spaces, providing the basis for biodiversity, the biomass for nutrient cycling, and the lush refuge for people and animals alike. People have repeatedly reported greater visual interest and restorative effects (e.g., reduction in negative feelings such as fear and anger and improvement of positive feelings such as relaxation) of vegetation, including trees and other plants, in all seasons in urban areas (Marcus & Sachs, 2014). Achieving balance in plant design is an “intuitive equilibrium”, characterized by dynamic elements of contrast, variety, and repetition (Boults & Sullivan, 2010, p. 55).

Studies have shown that people are aesthetically attracted to plant species diversity (Lindemann-Matthies et al., 2010), species evenness (i.e., relatively similar numbers of each plant species in an ecosystem), flower abundance, and flower color diversity (Graves et al., 2017). In grassland and meadow environments, people’s aesthetic appreciation increased with species richness (diversity) and species evenness (balance of plant numbers among different species) (Lindemann-Matthies et al., 2010). Furthermore, researchers identified social and cultural preferences of wildflower compositions, finding that aesthetic preferences, based on images, were unrelated to species richness, and were correlated with more abundant flowers, greater species evenness, and greater color diversity (Graves et al., 2017). Abundant flowering species and variety of flower, foliage, bud, seed, and stem color can create visual interest and contrast in the plant composition. Species evenness can be achieved in plant design by planting relatively similar massing's of species, much like the style of Piet Oudolf, who designs repetitive and rhythmic swaths of plant species, textures, forms, and colors (Kingsbury & Oudolf, 2016).

It is well known that greater species diversity often indicates a healthier ecosystem with greater complexity and resilience to external impacts (Walker & Salt, 2006). The massing of species also corresponds to beneficial habitat for pollinators, since groupings of a single species of flowers aids pollinators in finding forage quickly and provides 'flower constancy', allowing them to collect nectar and pollen from a single species during each foraging outing, which they prefer (Ebeling, Klein, Schumacher, Weisser, & Tscharntke, 2008). Native plants provide the most ecological benefit for other species (e.g., insects) and are often the most hardy because they are adapted to local climates and conditions (Tallamy, 2007; A. White, 2016). Including native plants with colorful blooms throughout the growing season, massing plant species in large swaths (minimum 5-8 species), and providing a diversity of color among blooms can be aesthetically pleasing and ecologically beneficial. It is evident that aesthetic preference can align with ecological health when both art and science are guiding plant design.

Altogether, these design principles and elements create a rich multisensory aesthetic experience. Stigsdotter and Grahn (2002) propose various healing garden 'rooms' with unique characteristics to be designed to provide a holistic experience to the visitor, including serene (e.g. harmonious textures, colors, forms), wild (e.g. naturalistic, reflecting native plant communities), rich in species (e.g. biodiverse), space (e.g. open, pastoral), the common (e.g. patio, deck, courtyard, place of convergence with basic amenities and open space), the pleasure garden (e.g. fragrant, idyllic plant species, sounds of running water), festive (e.g. colorful, art installations), and culture (e.g. reflective of local celebrations, customs, colors, fabrics and other crafts, historical artifacts). Sensory gardens provide inspiring ideas for garden rooms as well, intentionally catering to the five senses, including fragrant gardens, edible gardens, interactive touch gardens, auditory gardens, and visual gardens.

3.3.2 Recreation

Enhancing recreational benefits and opportunities are shown in Table 7, organized by elements of connectivity and access, movement and interaction, and rest and observation. The CES of recreation, provided by urban green spaces and infrastructure, can be enhanced through the design of GSI features to be inviting and interactive, to encourage play and exploration, and to provide enjoyable spaces to rest or be active in. Urban greenspaces, and especially greenspaces with a variety of land uses and water features have been shown to be associated with physical activity (Mytton et al., 2012) and to increase the psycho-social wellbeing benefits of physical activity (Sharma-Brymer et al., 2015). Design elements such as focal points, pathways, overlooks, seating areas, clear entryways and transitions, and playful features can invite visitors in and cause them to come back, creating more value and connection to place (Echols & Pennypacker, 2008). Providing increased opportunities for recreation include active and passive areas

Table 7. *Recreation Benefits: GSI Design Elements, Principles, and Practices*

<u>Design Element</u> **Design Principles**	**Design Practices**	**Potential benefits to wellbeing**	**Studies**
<u>Connectivity & Access</u> Transition Accessibility	Public accessibility: Easily accessible from surrounding areas - trails - open greenspace nearby - visual access (e.g., sitelines to water features)	Belonging Security	(Gobster & Westphal, 2004; Humpel, Owen, & Leslie, 2002; Moore & Hunt, 2012)
	Safety/Physical Accessibility: - ramps - walls, screens, railings - ADA compliant - Canopy vegetation and groundcovers	Belonging Security	(Cohen et al., 2015; Kuo & Sullivan, 2001; Moore & Hunt, 2012; Troy et al., 2012)
	Clear and discernible entryways & exits - gateways - pathways, boardwalks - curbing	Sense of place	(Kellert & Calabrese, 2015)
<u>Movement & Interaction</u> 'Hide & Reveal' Mystery & Complexity Scale Framing Mobility Security	Opportunities for interaction with water features and people - Weave pathways, bridges, boardwalks, etc. water path - Places to touch water, e.g., pools, waterfalls, rain chains	Curiosity/play Mental health Physical health Self-esteem Mood	(Barton & Pretty, 2010; Humpel et al., 2002; Kaplan & Kaplan, 1989; Kellert et al., 2008)
	Sense of journey, exploration, and play - Hidden elements & focal points -water, trees, lawn, trails, picnic areas - Recreational infrastructure: spaces to stretch, fitness stations, play features	Curiosity Excitement Play Self-esteem Mood	(Barton & Pretty, 2010; Dosen & Ostwald, 2016; Hurley & Stromberg, 2008; Kaplan & Kaplan, 1989; Kellert & Wilson, 1993; Schroeder & Louviere, 1999)
	Viewsheds with protection - Overlooks, decks - Viewpoints/'Shakkei points' - broad views with partially framed view - borrowed scenery, frame surrounding landscape features or distant features - Peekhole windows? - green walls?	Sense of place Mental focus & restoration Pleasurable Stress reduction Preference Refuge Safety	(Appleton, 1996; Biederman & Vessel, 2016; Dosen & Ostwald, 2016; Hartig et al., 2011; Li & Sullivan, 2016; Ruddell & Hammitt, 1987; Senoglu, Oktay, & Kinoshita, 2018; Stamps, 2008)

<u>Design Element</u> **Design Principles**	**Design Practices**	**Potential benefits to wellbeing**	**Studies**
<u>Rest & Observation</u> Occupying space 'Prospect & Refuge' (openness & safety) Shakkei	Places to rest with protection - Benches, seating walls - swings - tables, chairs - mounds, hills, berm earthworks - Walls, green walls, vegetation,	Physical health Mental health Safety Refuge Preference Pleasure	(Senoglu et al., 2018)
	Places to rest in groups - patios/courtyards - Seating walls	Connectedness Safety Refuge	(Kaplan & Kaplan, 1989)

to direct use of the system and to allow space for creative use. Echols and Pennypacker (2008) define three ways that visitors can recreate within GSI areas, including to view from nearby, to enter by coming into physical contact with parts of the system, and to play in with opportunities to engage and alter parts of the system.

GSI practices are often integrated into an urban streetscape or park and it is important that they are considered in the movement of people and materials. Connectivity, safety, and clearly marked entryways and exits of a stormwater treatment area are important for the recognition and success of a project. Echols and Pennypacker (2008) recommend walls, screens, plant massing to direct traffic, and use of bridges and boardwalks near GSI features to improve safety.

Safety is an important consideration to increase use and overall CES benefits of a greenspace; Cohen et al. (2015) found that park renovations, which were significantly associated with increased perceptions of safety, lead to increased park use and activity within the park. However, Humpel et al. (2002) found that accessibility to facilities, opportunities for activity, and aesthetic attributes had significant association with physical activity, but not weather or safety. Furthermore, respondents in a study revealed strong preferences to recreate in areas with water features in addition to a mixture of trees, mown grass, and infrastructure such as picnic areas and trails (Schroeder & Louviere, 1999). It is evident that GSI elements, including water features, vegetation, and opportunities to rest, can be integrated into recreational pathways to provide interesting, delight, and diversity in addition to air quality and cooler temperatures.

Recreational pathways can connect GSI features to nearby pedestrian destinations as well as to other GSI features in the landscape, creating easily accessible veins of similar and diverse urban landscape features. Pathways could weave strategically nearby stormwater treatment systems as well as crossing through and above waterways to provide interest and intrigue. Networks of trail systems that connect GSI features in urban areas can create spaces within urban contexts for users to move through, improving quality of life and value in the landscape.

Entryways to GSI practice areas can be defined by design cues such as arches, gateways, changes in path materials, and features with similar shapes, materials, and/or textures installed throughout the area to create a cohesive landscape pattern. Design principles to guide these elements include transition, framing, datum, and harmony (Boults & Sullivan, 2010).

Seating areas can provide places to relax amid sounds of water and lush green spaces. Benches, chairs, low walls, and playful swings can invite passersby to stop and enjoy the space. The design theory of ‘prospect and refuge’ can inform seating design to provide protection from behind in the form of vegetation, screens, or walls, and views in front of stormwater features and landscape features beyond utilizing design principles of shakkei, framing, and extension. Prospect Refuge theory is based on the evolutionary preference of humans for habitats that have open views (Savannah Theory) and protective features that provide shelter or hiding (Appleton, 1996). The aesthetic experience of landscape is thought to be subconsciously influenced by features that elicit prospects and refuges and therefore guide people's preferences and movement or rest in a landscape to favor 'edge' environments. There have been some empirical studies that find people preferred locations with nearby refuge, such as in meadows but near the forest edges (Ruddell & Hammitt, 1987), views of distant mountains (Stamps, 2008), and openness of a landscape, enhanced by 'shakkei' points, or observation points that frame borrowed scenery in the distance in Japanese gardens (Senoglu et al., 2018). The application of prospect and refuge theory in urban green spaces with GSI would focus on creating openness and viewpoints because the green space already functions as the refuge in the city, with sufficient protection of vertical elements and vegetation, like what was found in Japanese gardens in an urban setting (Senoglu et al., 2018). Shakkei, a design principle from Japanese Daimyo gardens, then becomes the leading principle to guide design of viewpoints that gaze over water and garden features with framed views of buildings or distant mountains and other landscape features beyond.

More important than prospect and refuge elements in urban green spaces may perhaps be elements of mystery and discovered complexity, characterized by the Hide and Reveal' Theory. Hildebrand expanded on the prospect-refuge theory to include elements that are associated with exploration potential, including mystery, complexity, enticement and illumination (Dosen & Ostwald, 2016). This theory can be traced back to Kaplan and Kaplan's (1989) information processing theory that suggests spaces with opportunities to gather or discover information allow for improved wellbeing (Dosen & Ostwald, 2016). Therefore, urban green spaces that have outlooks or viewpoints with partially framed or enclosed views with visual complexity in foreground to enhance feelings of safety and finally, a sense of mystery or discoverability is psychologically preferred (Dosen & Ostwald, 2016). Mystery and discovered complexity can be created with paths that wind and disappear behind vegetation or a focal point in the distance that draws you towards it such as an interesting tree or sculpture.

3.3.3 Social Capital and Stewardship

Social capital and stewardship benefits are illustrated in Table 8, organized by the physical spaces for people to come together and the participatory processes required to cultivate social capital and stewardship benefits. Social capital built by social connectivity (e.g., forming bonds and relationships) is an important CES in urban areas, critical for enhancing other benefits, such as sense of place and education (Larson et al., 2016). A study of two kinds of Sacramento parks-one made up of lawn and widely spaced trees and the other of community gardens—found that residents placed considerable value on the gardens for the associated activities and opportunities for socializing, demonstrating that vegetation and greenspaces "should not be seen as simply passive decorations, but as opportunities for active involvement by residents, and as a part of the life of a vibrant city" (Botkin & Beveridge, 1997, p. 13; Francis, 1987). There are often public misconceptions that all GSI is unattractive or ineffective due to the novelty and limited understanding (Rowe et. al., 2008). On the other hand, GSI projects that have a strong volunteer or civic component seem more popular due to hands-on educational activities, which can possibly lead to support for more GSI projects in the

Table 8. *Social Capital and Stewardship Benefits: GSI Design Elements, Principles, and Practices*

Social Capital & Stewardship <u>Elements</u> Design Principles	**Design Practices**	**Potential benefits to wellbeing**	**Studies**
<u>Places to gather</u> Utility Accessibility Observation	- Flexible space for local creativity and experiments - "Cultivate possibilities" Placemaking for different local knowledge and social networks to arise *Outdoor classrooms *Galleries, stages	Social interaction/ Connectivity Experimentation	(Bendt et al., 2013)
	-Biodiversity, reduction of impervious surfaces -Large trees, green space	Learning/capability	(Dennis & James, 2017; Sullivan, Kuo, & Depooter, 2004)
	- Basic amenities (e.g. garden tools, shelter, seating)	Learning/capability	(Dennis & James, 2017; Sullivan et al., 2004)
<u>Participatory</u> Transformation Collaboration Integrity Inclusive Responsive	- Community involvement in early planning stages *Value-mapping *Demonstration & media for public edu and awareness (e.g., landscape visualizations, photo-simulations, photos, imagery)	Social interaction/ Connectivity Belonging Identity	(Hurley & Stromberg, 2008; Kati & Jari, 2016; Rowe, Rector, & Bakacs, 2016; Roy et al., 2008)
	-Opportunities to engage *Less formal, looser frameworks to participate, e.g., art installations, political activity, business development events *Creative ways to engage public (e.g. sidewalk chalk, murals, school programs)	Social interaction/ Connectivity Belonging Identity	(Bendt et al., 2013)
	- Volunteer programs * "Adopt-a-Raingarden" maintenance programs	Social interaction/ Connectivity Belonging Identity	(Hurley & Stromberg, 2008)

future (Rowe et. al., 2016). GSI can be designed for and with residents to develop volunteer programs, such as Adopt-A-Raingarden, to involve local gardeners and others in the maintenance of diverse perennial gardens (American Rivers, 2016; CCRPC, 2018). This would allow for more abundant and colorfully blooming plantings than if maintenance depended solely on a municipal maintenance crew and would provide educational opportunities to involve community members.

In addition, large trees have been found to attract people outdoors and result in greater social interactions than communities without green space and trees (Sullivan et al., 2004). Stormwater street trees, such as tree cells or filter boxes, are a relatively simple GSI practice that provide many co-benefits.

Designing GSI with a goal of instilling a sense of stewardship for water resources in stakeholders requires participatory processes from the outset of a GSI project. Civic practice in urban green spaces is necessary to re-instill a genuine understanding of ecological processes that are deeply integrated into diverse activities, observation, and meaning among heterogenous urban populations (Bendt et al., 2013). Land use decisions must involve the public from the outset of a project to obtain all stakeholders goals and objectives if the project is truly to be sustainable and valued (Kati & Jari, 2016).

Bendt, Barthel, and Colding (2013) found the need for active participation and experimentation by citizens themselves and that planning and design must value and incorporate space for local creativity and experiments (Bendt et al., 2013). Finding mutual cultural values in public green spaces is important for sustainable urban development (Kati & Jari, 2016); therefore, preferences for plantings and siting GSI must reflect the diversity of values and uses present in an urban green space (Maraja, Barkmann, & Tscharntke, 2016). Kati and Jari (2016) propose a method for integrating diverse ways on knowing and valuing: value mapping, which considers many socio-cultural values from many stakeholders. Value mapping can then identify mutual values, understand disagreements, and move forward with a focus on mutual values. Problems in land use often arise when one group feels as if their voices are not heard and they have a strong attachment to place (Ernstson, 2013; Ernstson & Sörlin, 2013; Kati & Jari, 2016).

Landscape visualizations are a tool to integrate into participatory planning processes to clarify spatial components and temporal processes of GSI and support discussion and decision-making surrounding complex landscapes changes (Al-Kodmany, 2002; Tress & Tress, 2003). Visual renderings build participatory capacity and are accessible to diverse audiences because they provide a common language (Kwartler, 2005; Meitner et al., 2005; Shaw et al., 2009). Using images to envision planning decisions enhances citizen connection to community planning and encourages participation from the public (Sheppard, 2012; Warren-Kretzschmar & Tiedtke, 2005). It is important to involve community members in the outset of public GSI projects to encourage involvement, a sense of ownership, and potentially stewardship for projects that they feel they have a voice in (Philadelphia Water Department, 2014). Projects that affect community members who were not invited to participate in the process are often confronted with backlash or defensive responses (Galler, Kratzig, Warren-Kretzschmar, & Von Haaren, 2014), whereas accurate landscape visualizations of controversial projects often dissuade fears and alleviate resistance (Barbarash, 2008; Neto, 2006). Public participation is an invaluable component of successful landscape planning and it is vital to include community stakeholders in the decision-making process (Warren-Kretzschmar & Tiedtke, 2005).

Bendt, Barthel, and Colding (2013) found that less formal and looser frameworks for participation in public-access community gardens in Berlin led to greater involvement in the community and reached larger and more diverse numbers of people. By combining collective gardening with art, political activity, back-to-work programs, or business development, greater activity at the boundaries of these spaces occurs and the potential for bringing people who were not seeking engagement with nature can find themselves in ecological and culturally beneficial spaces (Bendt et al., 2013). GSI could be sited to be in high visibility areas, near flexible and open use public spaces, where users of the space could interact with stormwater treatment measures as an added benefit of being in the space and stormwater quality efforts could benefit from greater awareness and interaction.

Dennis and James (2017) found that biodiversity and learning/wellbeing in collectively managed urban gardens were highly synergistic and that lower percentages of impervious surfaces had a significant impact on biodiversity and participation, although participation did require a baseline percent of impervious surfaces (e.g., essential facilities). GSI provides an excellent opportunity to transform impervious surfaces or monocultures into biodiverse ecosystems that provide numerous ES and CES.

Design ideas to enhance public relations and social connectivity for GSI projects in urban areas include siting them in high visibility areas, use of clear and interesting interpretive signage, use of local materials, creation of educational and programming opportunities, and planning for regular maintenance (Echols & Pennypacker, 2008a). CES are enhanced by the participation of local populations, and GSI that is designed with the help of local stakeholders and for the local community can instill a stronger sense of connection and ownership.

3.3.4 Education

Although, there are less well-documented examples of education and sense-of-place directly pertaining to GSI, I present preliminary thoughts on how to connect GSI to these CES.

Approaches to enhancing educational and learning benefits in GSI are outlined in Table 9, organized by observational, guided, and collective learning. Educational benefits derived from GSI can be both implicit (i.e., based on observation) and explicit (i.e., interpretive signage). CES literature speaks more to the implicit learning opportunities that natural spaces provide, which are applicable to GSI in urban areas (Russell et al., 2013). However, explicit learning opportunities are also a key component to enhancing the value that people receive from ecologically-designed spaces; “This type of intervention might give people knowledge and experiences promoting greater aesthetic appreciation by calling attention to forms of stewardship that may not be readily apparent, or that may even be interpreted as a lack of care” (Gobster et al., 2007, p. 970).

Educational benefits of GSI can be enhanced by creating visible stormwater treatment features and interpreting the water trail through interpretive signage, interactive elements, and places to gather to provide outdoor classrooms (Echols & Pennypacker, 2008). Greater education can occur from descriptive narratives of the water trails and larger watershed they are connected to as well as aiding a positive experience of place from direct interaction and observation (Echols & Pennypacker, 2008a). Echols and Pennypacker (2008) found that combining visible stormwater treatment systems with signage maximizes the educational opportunity, based on an investigation of 20 stormwater treatment system designs.

Table 9. *Education Benefits: GSI Design Elements, Principles, and Practices*

Education Element **Design Principles**	**Design Practices**	**Potential benefits to wellbeing**	**Studies**
Observation learning Abstraction Hierarchy	- Visible water path - opportunities to interact with water path - abstract representations of water processes (e.g., stone and sand represent stream channel) -Proximity to schools and workplaces	Learning/capability Support other learning (e.g., classroom, workplace) (restorative, cognition, focus, productivity)	(Bratman et al., 2015; Dadvand et al., 2015; Hartig et al., 2011; Kaplan & Kaplan, 1989; Li & Sullivan, 2016; Wu et al., 2014)
Guided learning Utility Truth	- Interpretive signage (e.g., explaining underground infrastructure, identifying native plants) -Kinetic art -Educational/community events -Curriculum integration	Learning/capability Engagement	(Church, 2015; Rodie, Arens, & Szatko, 2018; Welker, Wadzuk, & Traver, 2010)
Collective learning Inclusive Participatory	- Proximity to educational institutions (e.g. school, library, daycare) - Volunteer programs (e.g., "Adopt-a-Raingarden")	Learning/capability Social interaction/ Connectivity	(Bendt et al., 2013; Moore & Hunt, 2012)

Making stormwater infrastructure features visible is an important part of demonstrating the functions and impact of GSI in urban spaces. Sculptural features and other unique elements can call attention to different parts of the system, such as sculptural gutter downspouts or scuppers, dynamic inlets or dissipation basins, and interactive swale conveyance systems. "Daylighting" the water trail as much as possible by bringing it above ground so that visitors can follow the path and observe the different stages of capture and treatment during a rainstorm is an important part of learning. Sculptural features can model or abstract larger landscape patterns, such as imitating local riverways and lake basins in the process of capturing, conveying, retaining, and treating stormwater runoff. Sculptures that use local materials or recycled materials can be used to symbolically depict the current and past water trail, for example, representing a keystone species of fish or utilizing old parts of underground storm sewer systems. Artful rainwater design can "employ environmental BMPs in designs that call attention to stormwater management in ways that educate and delight those who visit" in addition to managing stormwater runoff rate, volume, frequency, duration, and quality to promote ecological health of waterways (Echols & Pennypacker, 2008, p.268).

Vine Street (Artist, Buster Simpson) (Fink & Mackinnon, 2010; Geise, Dunphy, Ford, Hogben, & Waddell, 2004), Waterworks Garden (Artist, Lorna Jordan) (Echols & Pennypacker, 2008), and Mill Creek Canyon Earthworks Park (Artist, Herbert Bayer) (Calabria, 1995), all in Washington state, offer examples of this integration of art and ecology, where sculptural form and creative conveyance of stormwater that includes human interaction are integrated into stormwater basins, wetlands, cisterns, and infiltration gardens.

Interpretive signage is an important design practice that enhances the educational value of GSI projects by narrating the systems as visitors move through them (Church, 2015). There are several design recommendations to maximize the effectiveness and educational value of the signs. Echols and Pennypacker (2008, p. 274) found that "a brilliant signage system cajoles visitors into learning: first, the signs present small, digestible tidbits of information that can be read at a glance; second, the signs are located along major pathways, ensuring pedestrian encounters with the information; and third, their bright yellow color makes them highly visible." Key ingredients for successful interpretive signage is succinct and memorable pieces of the most important information about the GSI system, colorful and coordinated with recognizable symbols and color palettes to create cohesion and draw a viewer in, and easily accessible along nearby pathways and at natural resting points.

Another key element of interpretive signage for GSI projects is to depict the systems, especially the underground infrastructure, with photos and illustrations of conceptual graphics, such as section diagrams. An important part of the stormwater treatment processes occurs underground in filter media and soils and it is important to convey all the important processes occurring out of sight.

Proximity to educational institutions, such as schools and libraries, can increase opportunities for learning benefits to a wide variety of ages (Moore & Hunt, 2012; Rodie et al., 2018; Welker et al., 2010). Integrating the planning, design, implementation, and maintenance of GSI into school curriculum provides a real-world application to many science, technology, engineering, art, and math themes (Rodie et al., 2018; Welker et al., 2010). This supports Church's (2015) emphasis on multiple points of contact and diverse programming when integrating GSI in curriculum and engaging the general public.

3.3.5 Sense of Place

Potential benefits to one's sense of place as a result of GSI design are outlined in Table 10, organized by spatial and temporal, including seasonal and historical, understandings of place. There are no studies known about GSI elements' impact on viewers' sense of place and increased connection to larger landscape spatial and temporal patterns, but many design recommendations for artful and interpretive GSI include such elements.

Table 10. *Sense of Place Benefits: GSI Design Elements, Principles, and Practices*

Sense of Place Element **Design Principles**	**Design Practices**	**Potential benefits to wellbeing**
Spatial – Landscape/Basin Abstraction Shakkei Identity	- Connect to local landscape (e.g., soils, bedrock, land forms) -Earthworks (e.g., berms, swales, mounds) to represent hills, mountains, valleys - Abstract to local water bodies (e.g., riverways, lake basins, gorges, marshes) - Represent symbolic species (e.g., common plant, keystone aquatic fish species) - Use of regionally native plants that represent ecological plant communities found in nature	Sense of place Identity Learning/capability
Short Temporal - Seasonality Weather Climate Seasons	Plantings with year-round interests - Season-long blooms - Interesting foliage, buds, bark, etc. - Winter interest (e.g., dead seedheads, berries, textural bark, evergreens) Design for observation during rainstorms (e.g. sheltered seating areas to watch GSI)	Sense of place Identity Learning/capability
Long Temporal – History Identity Landscape change	-History of water use and management (e.g., recycle old stormwater infrastructure in sculpture) -Depict pre-development topography and water flows -Describe future goals of water quality and “green cities”	Sense of Place Identity Learning/capability

GSI provides hydrologic processes that are nested in a much larger watershed and landscape pattern. Design can depict these connections, and provide the viewer a greater sense of place, by nesting GSI practices in the larger landscape—both spatially and temporally—through representation, abstraction, and connection. Sculpture, imagery, materials, and stormwater treatment feature forms can represent local waterways, basins, and wetlands. Local plant communities can be represented with regionally native plants that grow in similar environments and tolerate GSI conditions.

Multifunctional GSI design should provide visual interests year-round and in all weather conditions. Plantings can include season-long blooms to provide colorful and abundant flowering species as well as provide forage and shelter for native pollinators and birds. Other seasonal interests include buds, foliage, textural bark, and berries that change with the seasons. Designing for all weather conditions is key, especially providing shelter so that viewers can observe GSI in action.

Finally, connecting viewers to the history and future of land uses, including pre-development topography and hydrologic functions, past stormwater management methods, and future goals of water quality and "green cities" are important to nest ourselves within larger timescales.

Environmental art and interpretive signage can play a role in visual ecology, i.e., making ecology more visible to the viewer and their dependence on ecosystem functioning more evident (Thayer, 1976, 1998; van Bohemen, 2002). Potential art integrations include involving artists in discussions during the design process, integrating sculpture into GSI that is functional and beautiful, and representing larger landscapes and processes through visual imagery and sculpture (van Bohemen, 2002).

3.4 Conclusion

Multifunctional GSI benefits both ecosystems (S2E) and people, providing both biophysical and cultural ecosystem services. GSI transforms urban areas to be part of the solution to stormwater management, not just the problem, by providing hydrologic processes of conveyance, capture, retention, plant uptake and evapotranspiration, percolation, groundwater recharge, and water filtration, benefitting aquatic ecosystems downstream. GSI also provides an opportunity to integrate pockets of green space and biodiversity throughout an urban landscape, providing habitat for wildlife and people. Green spaces provide numerous benefits to the health and wellbeing of urban-dwellers and can be enhances through multifunctional design to reach wider audiences and cultivate deeper connections to nature. Designing multifunctional GSI to provide enhanced aesthetic, recreation, social capital, stewardship, education, and sense of places benefits can increase the value of GSI and re-connect people to the ecosystems on which they depend, alleviating issues such as nature deficit disorder and extinction of experience. The GSI design guidelines presented in this study provide a starting point to create ecologically vital and culturally significant streetscapes, parks, buildings, and commons.

Culture and ecology must cohabitate for ecologically functional urban areas to be sustainable and regenerative because people tend to care for the places they find beautiful, so aligning ecological health with aesthetically valued landscapes is essential to establish care and stewardship of vital systems that support both human and planetary health (Nassauer, 2011).

Multifunctional design can make the ecological beautiful as well as instill greater value in ecological designs by teaching people about the vital processes occurring (Gobster et al., 2007). Design can help to direct the eye and teach us about the ecological web that we participate in; it can create a "landscape language" that connects more deeply to the ecological processes taking place around us. Anne Whiston Spirn writes,

> "The language of landscape recovers the dynamic connection between place and those who dwell there. …Significance is there to be discovered, inherent and ascribed, shaped by what sense perceive, what instinct and experience read as significant, what minds know. …The power to read, tell, and design landscape is one of the greatest human talents; it enabled our ancestors to spread from warm savannas to cool, shady forests and even to cold, open tundra. But now, the ability to transform landscape beyond the capacity to comprehend it threatens human existence. …To recover and renew the language of landscape is to discover and imagine new metaphors, to tell new stories, and to create new landscapes. …[to] shape landscapes that sustain human lives and the lives of other creatures as well, can foster identity and celebrate diversity." (Spirn, 1998, p. 17-25)

In an effort to recover and renew our relationship to the vital water processes that we impact and depend upon, designing water runoff, capture, storage, infiltration, treatment, and reuse processes to be visible, beautiful, dynamic, and part of our everyday lives, is to uncover and celebrate a piece of the landscape language. Interactive and beautiful spaces that both demonstrate and describe the water processes occurring can help develop 'ecological literacy' and give people the tools to begin to recognize these processes elsewhere in the landscape, connecting the dots and nesting ourselves in spatial and temporal patterns, revealing a greater understanding of how we inhabit and impact the environment around us (Gobster et al., 2007; Nassauer, 2011; Orr, 2011). Multifunctional CES design of GSI can weave new stories of water into urban environments, creating new landscapes that thrive, culturally and ecologically.

The design practices and principles presented reflect Ebenezer Howard's central idea to his book, *Garden Cities of To-morrow* (1902,1946, p. 48), that "human society and the beauty of nature are meant to be enjoyed together. The two must be made one…" by reintegrating vital ecological processes and benefits into daily life (Hartig et al., 2011). The process of redesigning streetscapes and public spaces to reclaim rainwater and snowmelt with healthy soils and biodiverse flora and reintegrate these important processes into our daily paths and minds is the graceful and necessary adaptation for humans to continue to thrive in urban areas.

3.5 References

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5. Appendices